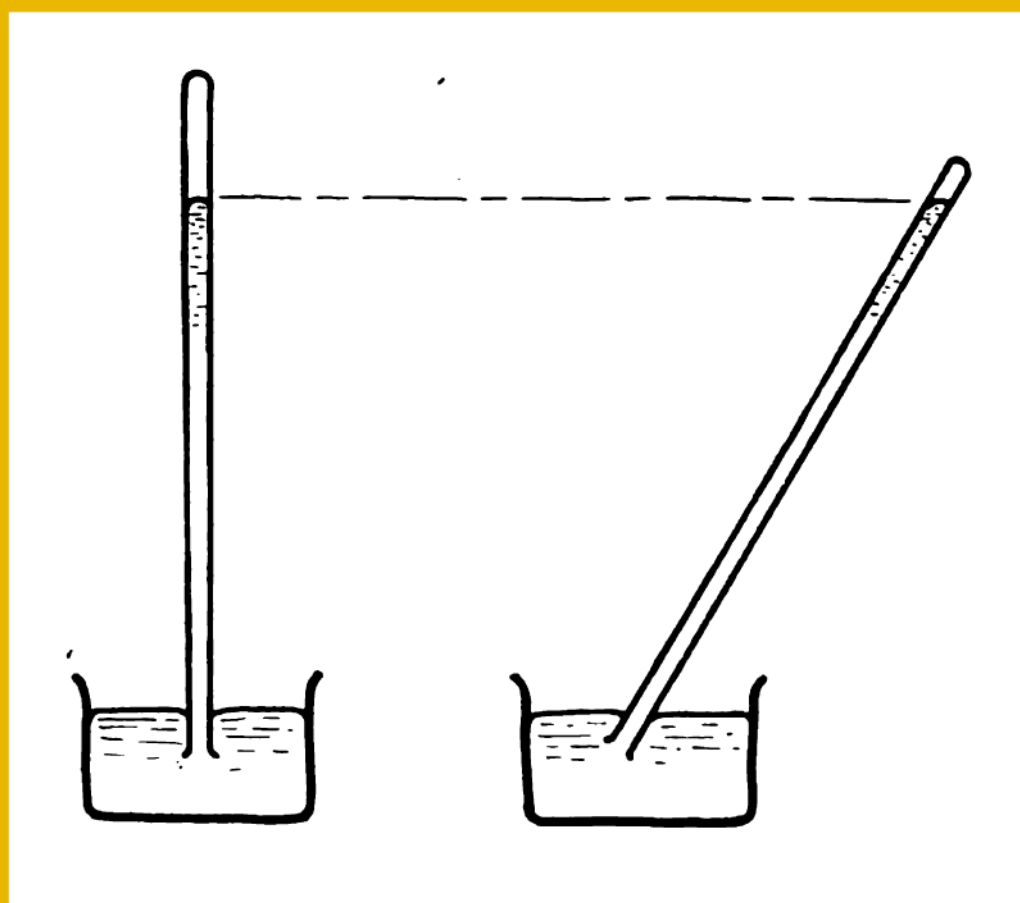


INVITATION TO EXPERIMENT

IRA M. FREEMAN,



INVITATION TO EXPERIMENT

IRA M. FREEMAN

is co-author with

ARTHUR E. HAAS *of*

ELEMENTARY SURVEY OF PHYSICS

"This book will be useful to all those who want to keep abreast of the new developments in the world of physics and is especially recommended for those who wish to get an enjoyable introduction to the fundamentals of this fascinating science."

—The Yale Scientific Magazine.

"As a text the book is excellent. As a means of general information on the subject it should appeal to certain classes of readers. As a book for reference it should have wide application."

—Journal of the Franklin Institute.

"Here is a non-mathematical presentation of the field of physics in concise form."—*Science News Letter.*

Published by

E. P. DUTTON & CO., INC.

INVITATION TO EXPERIMENT

By

IRA M. FREEMAN, PH.D.

With Photographs and Drawings by

MAE AND IRA FREEMAN

NEW YORK

E. P. DUTTON & CO., INC.

— 1940 —

COPYRIGHT, 1940
BY E. P. DUTTON & CO., INC.
ALL RIGHTS RESERVED



First Edition

PRINTED IN THE UNITED STATES OF AMERICA
BY THE WILLIAM BYRD PRESS, INC.
RICHMOND, VIRGINIA

CONTENTS

	PAGE
BY WAY OF INTRODUCTION	9
CHAPTER	
I THE STUFF THE WORLD IS MADE OF	13
2 STILL WATERS	23
3 NOW, TAKE THE AIR	31
4 MECHANISM	39
5 MATTERS OF GRAVITY	46
6 THIS DYNAMIC UNIVERSE	56
7 AIR IN ACTION	66
8 GYRATION	73
9 OF DROPS AND BUBBLES	79
10 SOUND COMMENT	87
11 MUSIC IN THE AIR	94
12 UP AND DOWN THE THERMOMETER	105
13 WHEN MOLECULES DANCE	119
14 WHAT STRANGE ATTRACTION	129
15 ELECTRICITY AT REST	137
16 ELECTRICITY AT WORK	152
17 SHADOWS AND REFLECTIONS	169
18 LIGHT ERRANT	187
19 BEYOND THE RAINBOW	199
20 LIGHT AND SIGHT	221

LIST of PHOTOGRAPHIC ILLUSTRATIONS

	PAGE
Honey is a viscous liquid	18
A paper cylinder can support an incredible load	18
Submerging a stone decreases its weight	26
Not "suction", but pressure of the outside air, collapsed the can	32
Galileo Galilei, 1564-1642. He was the founder of experi- mental science	33
Isaac Newton, 1642-1727. The fruits of his insight will live for all time	49
The position of the center of gravity makes this balancing feat possible	52
The box rolls uphill, but its center of gravity goes down .	52
Marbles striking a stationary row drive off an equal num- ber from the end	64
Airplane ready for test in the full-scale wind tunnel . .	68
Air moving across the top surface holds up an airplane wing	68
Blowing makes the card cling to the spool	70
Smooth air flow means low resistance to motion	70
The huge stabilizing gyroscope on the " <i>Conte di Savoia</i> " .	76
The play of surface tension: successive stages in the splash of a drop of milk	80
Air from the contracting bubble blows the flame aside .	85
Two sets of waves interpenetrate without destruction .	87
Four ears are better than two for locating hostile aircraft .	103
Stretched rubber is unique in contracting when heated .	111
Heat conductivity of the wire screen prevents the flame from going through	111
There is nine times as much below water	121
The wire cuts through the block of ice, but leaves it intact	121
Condensation is imminent	125

	PAGE
Condensing moisture outlines the paths of atom fragments	125
A knitting needle becomes a magnet	130
The magnetized knitting needle directs the movements of the ballet	134
Bits of iron arrange themselves along the lines of magnetic force	134
A rubbed comb attracts a stream of water	138
The equivalent of a billion rubbed combs	144
From it, flashes of lightning ten feet long	147
Boulder Dam: the power of nearly two million horses .	157
The compass needle swings aside when a current flows through the coil	161
A magnet powerful enough to lift heavy loads	162
Waves originating at A appear to come from B after reflection	178
The candle, reflected from the glass plate, appears to be burning under water	178
A silvered ball is an unflattering mirror	185
Crescent-shaped patch of light reflected from a concave surface	185
Passing through the glass, light is bent aside and the penholder appears broken	189
A beam of sunlight internally reflected by a water surface .	189
Light "piped" along a transparent rod by internal reflection	193
Modern binocular research microscope	193
Apples, bananas and green peas illuminated by green light (above), and by red light (below)	203
Each substance has a characteristic pattern of spectrum lines	207
Landscape photographed by ordinary light (above) and by infra-red light only (below)	211
The spot pattern produced by X-rays passing through a crystal reveals the arrangement of its atoms	217

BY WAY OF INTRODUCTION

ONE of the most remarkable social and cultural phenomena of recent years is the steadily increasing interest in scientific matters on the part of the general public. The wide-eyed wonder at the “mysteries and marvels of modern science” which was the characteristic reaction of the public several decades ago is being replaced to a gratifying extent by intelligent inquisitiveness and serious interest. At the same time, popular science magazines of the “startling and amazing” stamp flourish in increasing number, advertisers prate of the “scientifically proven” merits of their product, and charlatans continue to sell such diverse products as horoscopes and rejuvenation pills.

Happily, scientists themselves are becoming aware of the need for addressing themselves to people at large, for interpreting the work of science to the average man. As a direct consequence, a considerable amount of meritorious writing on the interpretation of science has been published during the past few years. Much of this literature has tended to dwell unduly on the latest and most imposing achievements of pure and applied science—the whipped cream of the subject—supplying only sketchily if at all an exposition of the fundamental concepts on which the imagination-stirring fruits of modern scientific achievement are based.

It is natural that writers should slight what seem at first glance less intriguing, less interesting topics in favor of those whose novelty and wonder attract immediate attention. But this difference is merely superficial. Certainly—with a little explanation—a lump of iron is fully as remarkable as a filterable virus or the latest synthetic plastic, and gravitation is no less wonderful than cosmic rays or vitamins.

INVITATION TO EXPERIMENT attempts to elucidate some of those great generalizations which form the basis of science and its varied contributions to modern life. Not only are such principles fundamental to a true understanding of the devices that make living in this age what it is, but they are precisely the ideas that the layman can most readily grasp,—the features that are best able to convey to him the true spirit and meaning of science.

As the title indicates, this book seeks to introduce these principles by means of simple experiments which the reader can perform with ordinary objects such as rulers, tumblers, rubber bands, mirrors, etc. It is intended to be neither a “how-to-do-it” book nor a collection of tricks and paradoxes, but an exposition for inquisitive people of all ages who want simple, direct answers to questions about their surroundings,—answers that they can verify for themselves without struggling through involved, technical explanations or abandoning themselves to soothing but often misleading analogies. As Andrade and Huxley so aptly point out in *THE EARTH AND MAN*, “Science means finding out how things actually *do* happen, not laying down principles as to how they *ought* to happen.” Formal scientific research, pursued in elaborately equipped laboratories, is an activity reserved for the few, but it is quite possible for anyone lacking the special skills and technical devices of the trained scientist to discover for himself the things that make the universe “tick.”

The style of the book is purposely informal. Any use of unacademic or colloquial language is in the interest of clarity, directness and simplicity.

Finally, a hint as to how to approach this book: Many people, perhaps because of unfortunate experiences at school, have the impression that there is something inherently re-

mote, difficult and forbidding about science. Diffidence prevents them from effectively pursuing and enjoying what might otherwise be a fascinating and absorbing subject. Don't approach what follows in a spirit of trepidation. There is a chance that you may learn something new and have a good time doing it.

IRA M. FREEMAN

1

THE STUFF THE WORLD IS MADE OF

IF we look about and examine the material things surrounding us, we find them to be **solid** like iron or wood, **liquid** like water or oil, or **gaseous** like air or steam. These are the three states of matter. Think of a solid object as one that keeps a definite shape and occupies a definite **volume**, or amount of space. A liquid is a bit freer; it still has a definite volume, and resists attempts to force it into a smaller space, but it is quite shapeless. A glassful of water will take the shape of any vessel into which it is poured, but it always has a distinct top surface. A gas is least constrained of all three; it has neither a precise shape nor a definite volume. Not only will it conform to the shape of any vessel into which it is put, but it will always fill the container completely. It has no exact boundary of its own.

In many cases we are familiar with a single substance in all three states. Ice is merely water in the solid state. Raise the temperature and you have liquid water and finally steam, or water in the gaseous state. Ordinarily we think of air as a gas, but at about 310 degrees below zero it becomes a bluish liquid. Iron, usually a solid, becomes a liquid in a foundry and exists as a gas in the sun and in the stars.

All matter, regardless of what its state may be, occupies space and jealously resents the intrusion of other matter. If you have ever struggled through a crowd or accidentally bumped into a table or chair you know that this is so. Science uses a long word to describe this obvious and universal prop-

erty of matter: **impenetrability**. It means simply that no two things can occupy the same space at the same time. A boat pushes aside the water of the ocean and a balloon displaces the surrounding air.

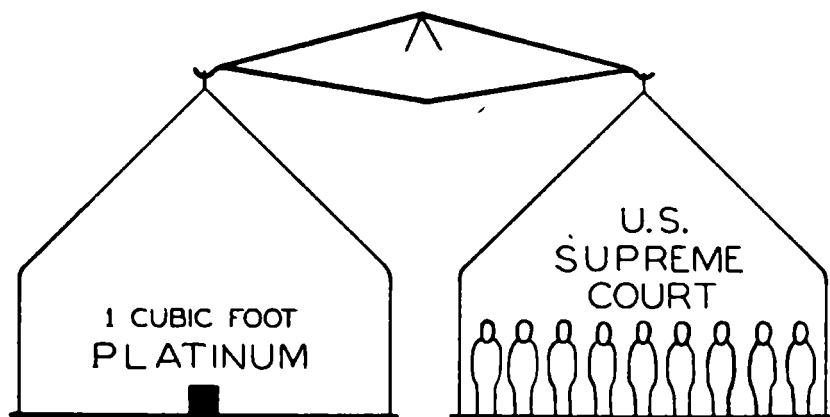
But not all situations are so obvious. Fill a tumbler brim full of water. Then, if you're careful, you can put in a considerable quantity of salt, a little at a time, before the water overflows. How do you explain it? We're so accustomed to thinking of water as something that completely fills the space it takes up that this seems truly a puzzle. The only way out is to conclude that water isn't really the continuous substance it seems to be; it must actually be "full of holes." It is found that water—in fact, any substance—is very porous, the pores being the unbelievably tiny spaces between the molecules which compose it.

However, if you carefully lower a stone into a glass filled with water there will be an overflow, and the volume of water running out will be exactly the same as the volume or amount of space occupied by the stone. In fact, this is a convenient way to measure the bulk of an irregular body. We commonly measure volume in cubic inches or cubic feet. A marble may cause an overflow of perhaps half a cubic inch of water—about a thimbleful. If you decide to get into a bathtub that is brim full, about two cubic feet of water will flow over the edge when you are completely immersed. The experiment is not recommended, for it may prove unpopular with your neighbors on the floor below.

Even "thin air" resents the ingress of other matter. Float a cork on water in a basin and push an inverted tumbler down over it. The water surface inside the glass goes down, as shown by the motion of the cork. It is the air within that prevents the water from entering this model diving bell,

although it does come in somewhat, due to compression of the contained air. The same principle is used in underwater tunnel construction. Air compressed to several times its normal pressure completely prevents water from entering the workings.

Besides occupying space, all material things have another property in common: they have weight. What we mean by the weight of a body is really the force of the earth's gravitational attraction for it, and that's something quite independent of how much space it occupies. Merely call to mind that venerable catch-question, "Which is heavier, a pound of feathers or a pound of lead?" The answer, of course, is that the weights are the same—one pound—but the space occupied by the feathers is much greater than that taken up by the lead. Scientifically, we say that lead has a greater **density** than feathers, meaning simply that a given volume of the metal, say a cubic foot, weighs more than the same bulk of feathers. Water, for example, has a density of about 62.5 pounds per cubic foot, for that's how much a cubic foot (about two pailfuls) weighs. The same bulk of air, on the other hand, weighs only a little over an ounce and a quarter. At that, the air contained in a medium-sized room weighs as



Justices in the balance

much as an average person. Mercury is one of the densest liquids, 13.6 times as dense as water. Platinum is one of the densest of all substances, and you'd be in a pretty predicament if someone offered to make you a present of a cubic foot of this precious metal on the condition that you carry it home yourself. It would weigh over two-thirds of a ton, or about as much as nine men.

While it is true that matter defends its domain of space, it can be made to yield somewhat by applying force. We say, then, that matter is deformable. A solid body can be bent, stretched, twisted or compressed. Its molecules hold on to each other tenaciously, but they can to some extent be forced closer together or pulled farther apart. When a wire is bent, the molecules on the outside of the bend are separated a little more than usual while those on the inner side are forced closer to each other.

Liquids are practically incompressible. Even at the tremendous pressure existing six miles down, ocean water is only about one per cent more compressed than at the surface. Gases are much more compressible than either solids or liquids. The air contained in an automobile tire occupies only one third as much space as it did before being pumped in.

Besides resisting compression, liquids and gases also resent being made to flow. This is called **viscosity**. It's what molasses has a great deal of in January!

How strong is a piece of paper? You can tear a single sheet with very little effort, but twist it into a rope-like form and it becomes strong enough to lift a flatiron or a chair. The cables that support an elevator or a suspension bridge consist of many strands of thin wire, each by itself not capable of supporting much weight, but strong in their co-operative effort.

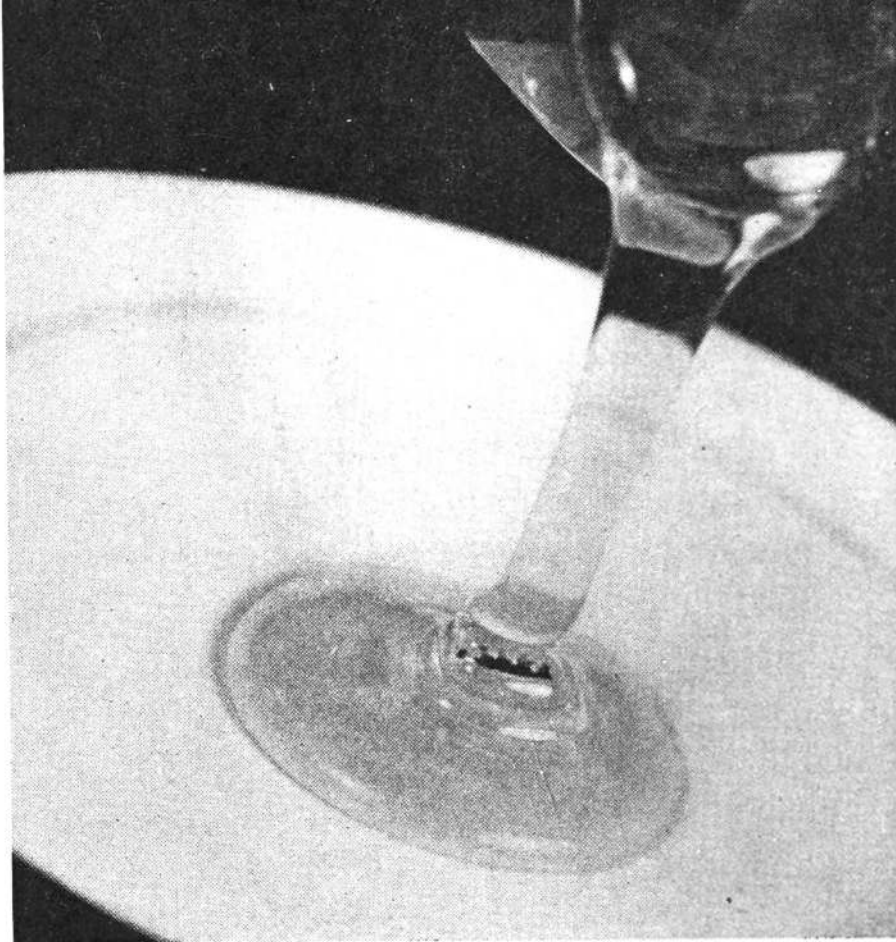
A sheet of letter paper will immediately buckle if you try

to stand it on one edge; but roll it up into a cylinder, slip a rubber band on to hold it, and not only will this column stand alone but it can be made to support several books placed atop it, as the picture shows. When the column is overloaded, diamond-shaped indentations appear on its surface and it collapses. An equally strong solid post of this material would weigh about ten times as much as the hollow cylinder. Structural engineers use these principles in designing skyscrapers and bridges. Lightness is combined with strength by giving structures the proper form.

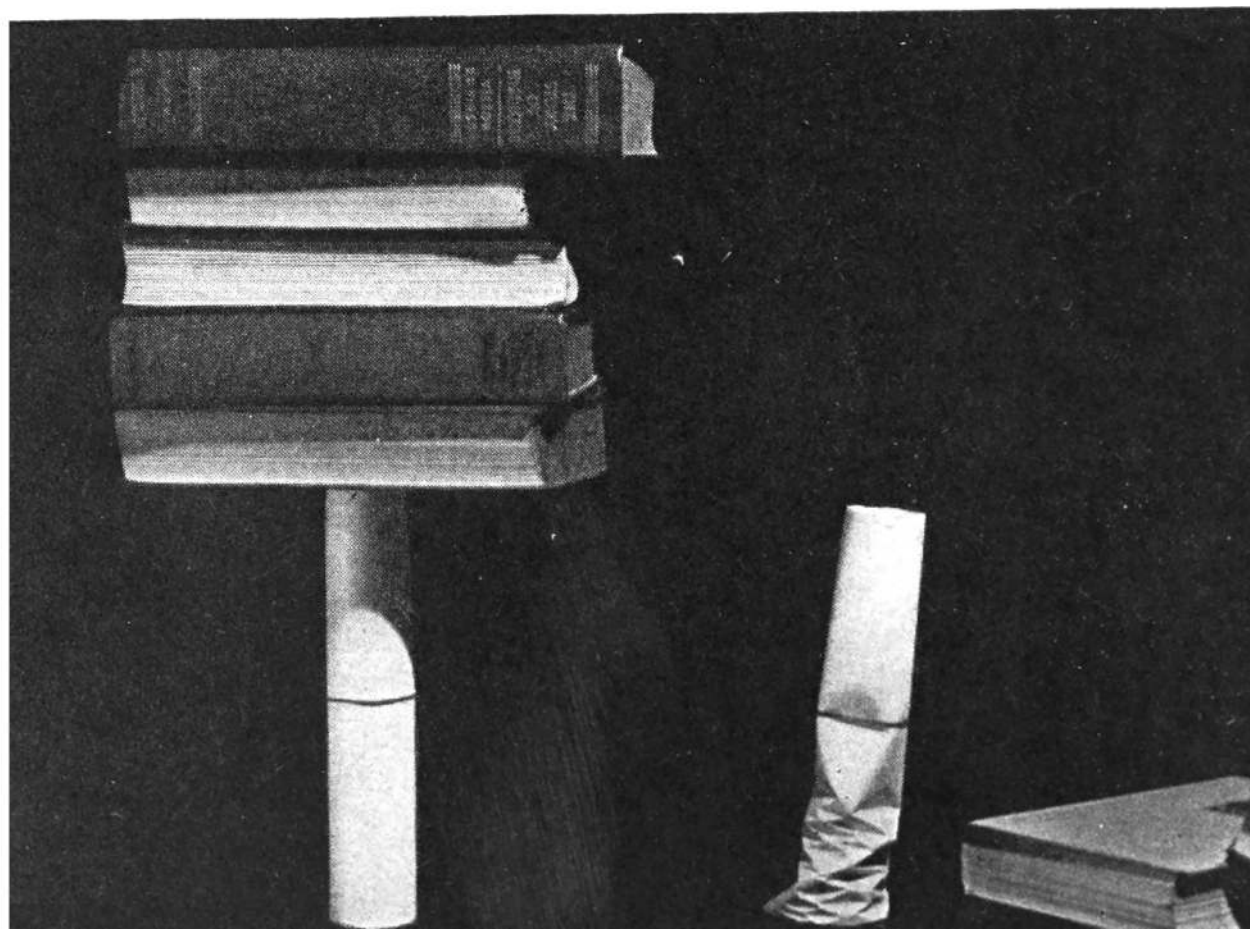
A straight piece of wire is much less stretchable than a rubber band, but by winding the wire in the form of a spiral spring, it can be made to “give” a convenient amount when moderate forces are applied. If a light spiral spring is available, hang it from the edge of a shelf. Attach to the lower end, one by one, a number of equal weights such as spoons. Mark each position of the lower end of the spring on a card placed behind the arrangement, and note that equal increases in load produce equal stretches. This behavior is true not only for stretching, but for all sorts of elastic deformations—twisting, bending, etc. In every case, the yield is in proportion to the applied force. For this reason you find that the divisions on the dial of a spring scale are equally spaced. Using a rubber band in place of the spring, you will now find that equal increases in load produce greater and greater stretches. Steel is considered to be more perfectly **elastic** than rubber because of its simpler behavior under such conditions; rubber, we say, is more **resilient**.

Hardness is another interesting characteristic of solids. You can scratch a piece of chalk with your fingernail, but the chalk is not able to scratch the nail. Your fingernail, in turn, is unable to make the least scratch on a penny, but the

*Honey is a
viscous liquid*



A paper cylinder can support an incredible load



coin can abrade your nail. A piece of glass scratches the coin, but is not scratched by it. We say that glass is harder than copper, copper harder than your fingernail, and this in turn is harder than chalk. By continuing such experiments it is found that steel is harder than glass, sand is harder than steel. Hardest of all substances is the diamond. Nothing can abrade it—except another diamond. Industries use diamond-tipped tools for precision work.

The ancients, who continually indulged in “armchair philosophy” instead of carrying on experiments, propounded this question: Suppose you break a bit of stone in two, then take



Is there a limit?

one of the pieces and break it in two, and so on. Is there any limit to how far you can go? Some of the keener philosophical minds happened to hit on the correct answer: The process of subdivision cannot be continued forever. Eventually you would have a speck no larger than the ultimate **molecules** of which the substance is made; if you could by some

means cleave a molecule, the substance would lose its identity altogether.

But molecules are such tiny things that for all practical purposes matter seems to be infinitely divisible. A single drop of ink will perceptibly color an entire basinful of water; a teaspoonful of salt will impart a noticeable taste to many gallons of water; a drop of perfume will scent thousands of cubic feet of air. An even more sensitive way to show the great divisibility of matter is to throw a little table salt "dust" onto a lighted burner. The yellow color, persisting a few seconds, is evidence of the presence of sodium—one of the constituents of common salt. A single crystal of this substance would be sufficient to color perceptibly a million or more gas flames.

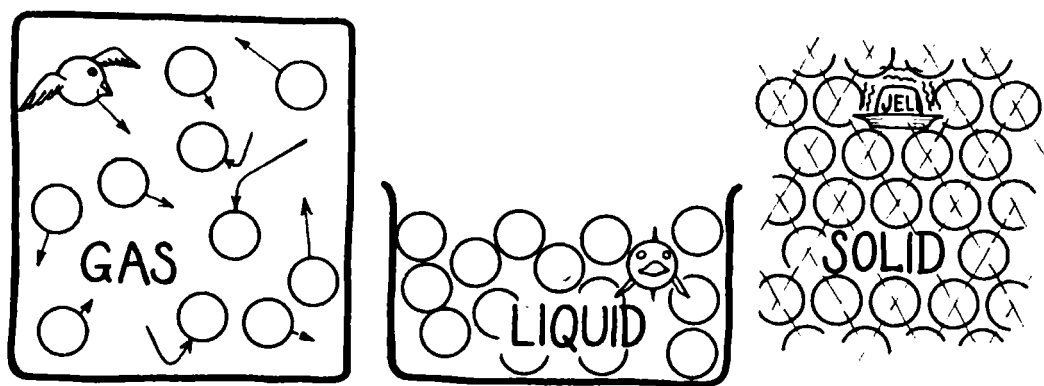
Are molecules real? The smallest particle that can be seen in a powerful microscope may consist of a million molecules, or even more. No one has ever seen a single molecule, so how do we know that such things exist? Science must often go beyond the range of our puny and imperfect human senses, and seeing is not always a prerequisite to believing or knowing. For example, if you should hear a sudden, loud report, accompanied by a flash of fire from the muzzle of a hunter's gun, followed by the sight of a rabbit dropping in its tracks, you would infer at once that a bullet killed the animal, although the bullet itself was not seen by you at all. So it is with our evidence for the existence of molecules; indirect, to be sure, but inescapable, and often more certain than the direct testimony of our eyes, which is sometimes misleading (see Chapter 20).

From an amazing variety of data, cemented together by strict mathematical reasoning, science has not only concluded that all matter is composed of molecules, but has found it possible to weigh, measure and count these tiny individuals.

It is found that there are over 400 billion billion molecules of oxygen and nitrogen in a cubic inch of air! Eighty million of them, if placed in a row side by side, would extend a distance of but one inch.

Further, it is known beyond all question that the molecules of every substance are in a constant state of motion. The higher the temperature, the faster they move. Air molecules at ordinary temperatures are moving at an average speed of nearly one third of a mile per second, and each one collides with its neighbors five billion times each second. These facts are no mere guesses; they can be verified beyond all reasonable doubt.

In a gas, the molecules are quite free to fly about, colliding with each other and with any object exposed to the gas. This continual bombardment manifests itself as the **pressure** exerted by the gas. When a gas is compressed, the flying molecules are crowded into a smaller space, and so they hit the sides of their container more frequently and exert more pressure. In a liquid, the molecules are held close to each



The perpetual unrest of molecules

other by forces of attraction—so close that it is almost impossible to compress the liquid—that is, to pack the molecules tighter. But still they are free to slide over each other, and

still they are in constant motion. In a solid, the molecules are even more tightly bound together and are arranged in regular order—the **crystal structure** of the solid—but even here they continue to vibrate about their appointed positions.

Of such things is our material world composed.

2

STILL WATERS

A liquid exerts pressure on the sides of its container. To show this, punch several nail holes at various heights along the side of a tin can, place it in a pan or sink, and fill it with water. A curved stream of liquid will issue from each opening, but the streams coming from the lower holes will reach out a greater distance, showing that the farther below the surface of a liquid you go, the greater the pressure.

We know that a stationary liquid exerts pressure because of its weight, but the remarkable fact is that at any point in the liquid the pressure is exerted equally in all directions—sidewise and even upward, as well as downward. You can convince yourself that water exerts an upward pressure simply by pushing the closed end of a tumbler beneath the surface of a bowl of water. In this case you will actually feel the upward thrust which the liquid applies to the bottom of the glass.

Exactly what is pressure? In everyday affairs, we use the terms “pressure” and “force” rather loosely; here we must be more careful. Pressure is the force applied *per unit area* of surface. To put the matter rather pointedly, it is what makes sitting on a tack less comfortable than sitting on a soft chair; the *force* applied is the same in both cases, but the area over which it acts is much less in the first instance, so the *pressure* is much greater.

Imagine a tall, tubular vessel whose cross-section is just 1 square inch. Suppose we pour 2 pounds of water into it.

Then the pressure on the bottom of the vessel will be 2 pounds per square inch,—merely the weight of the liquid distributed over an area of 1 square inch. If the same weight of water is poured into a vessel whose bottom has an area of 4 square inches, the 2 pound force will be spread over 4 square inches, so that the pressure is now only $1/2$ pound per square inch. It is found that the pressure at any point in a liquid, whether at the bottom or only part way down, depends merely on the depth of that point below the top surface of the liquid. The pressure at the bottom of a tumbler filled with water proves to be about $1/7$ of a pound per square inch. A mile beneath the sea, the pressure is 2,356 pounds per square inch; when Beebe's diving ball was half a mile down, it was being subjected to exactly half this pressure. This is still over half a ton of push on each square inch of surface, and only the strongest steel sphere can withstand such stress.

However, we know that queer varieties of fish live at much greater depths. How are they able to resist the crushing effects of these great pressures? The answer is that there is an equally great pressure from within their bodies, since the fluids in the tissues are under this same pressure, so the outside stress is counterbalanced and is not felt at all. But often, when one of these creatures is caught and pulled to the surface too rapidly, the internal pressure does not have enough time to reduce to the outside value, and the poor fish literally blows up!

You can easily exert tremendous pressures, using only moderate force, by making the surface to which the force is applied very small. An ordinary pin, when pressed against a hard surface, is in contact with it over an area of something like $1/100,000$ square inch. If you push down on the

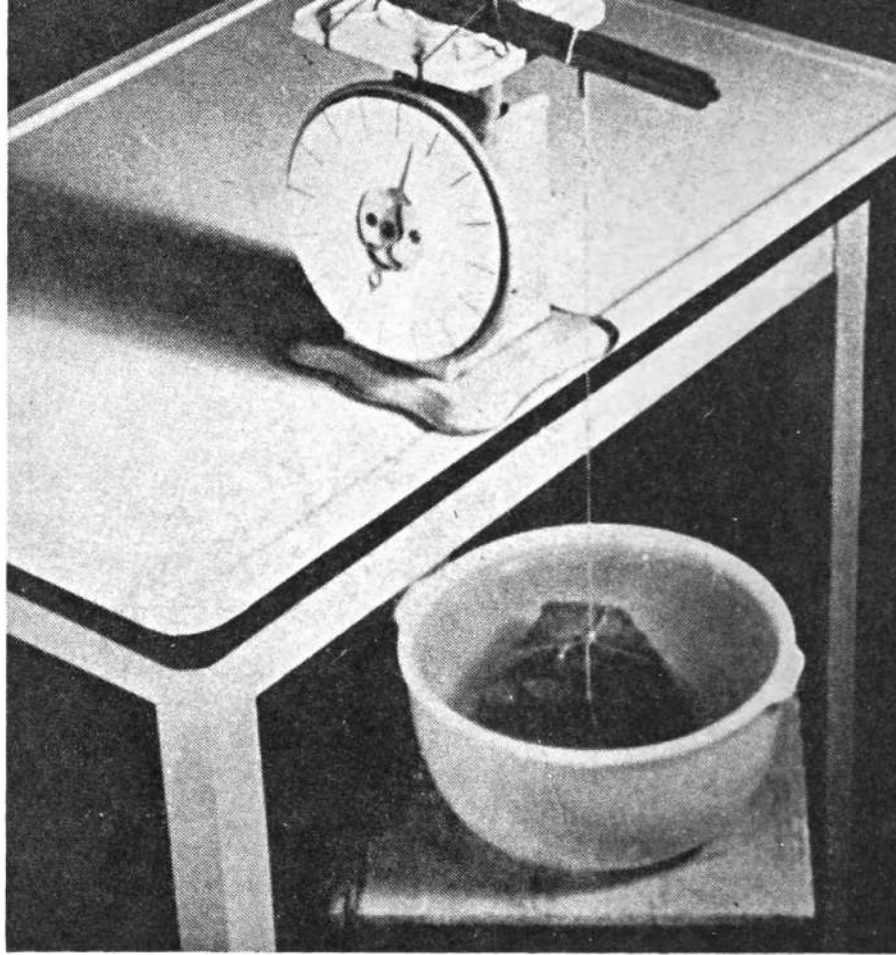
pin with a *force* of only one pound, the pressure on the surface of contact is then 1 divided by 1/100,000, or 100,000 pounds per square inch,—over seven times the water pressure at the deepest spot in the ocean.

Ask the average person why a water surface is flat and horizontal and he'll probably say very glibly: "Because water seeks its level." Knowing what you do about water pressure, you now can give your unscientific friend a detailed explanation: Inasmuch as pressure changes with depth, the water would tend to flow from one place to another if there were any difference in level. Hence there cannot be any such difference if the liquid is at rest, and so the entire surface must be flat.

An interesting question to ask doubting people is this: "Where does the liquid stand higher, in the teapot itself or in the spout?" At first glance, it seems that the water ought to stand considerably higher in the spout, in order to counterbalance the greater amount of water contained in the pot itself. But just remember what we found out about pressure,—it depends only on the vertical depth below the surface, and not at all on the size or shape of the vessel. If the water is stationary, the pressure must be the same on both sides of the place where the spout is attached to the teapot,—otherwise the liquid would flow from one to the other. This does not occur and so the pressures must be equal, the levels must be the same. Try it, if you're still unconvinced.

We already saw that water exerts an upward force on the bottom of any object immersed in it. Nearly twenty-two centuries ago, the venerable Greek philosopher ARCHIMEDES discovered exactly how this works when he observed that on getting into his bath he appeared to become lighter in weight as he submerged his body. It suddenly occurred to him that

*Submerging
a stone
decreases
its weight*



any object immersed in water must appear to lose an amount of weight equal to that of the water it displaces, or pushes aside. So thrilled was he by this discovery that he is said to have run home to test these findings, forgetting in his excitement to put on his clothes.

You can test ARCHIMEDES' principle yourself if a balance or household scale is available. Weigh any solid, non-porous, heavy object—say a large stone. Place a bowl or pail in a dishpan and fill the bowl brim full of water. Now hang the stone from the balance, as shown in the photograph, and weigh it when it is immersed in water. The weight is now found to be less than before, due to the buoyant effect just mentioned. Meanwhile, the stone has caused its own volume of water to overflow into the dishpan. Remove the bowl and weigh the dishpan with its contained water. Spill out the water and

weigh the dishpan alone. The difference is the weight of the water, and you'll find that this is just about the same as the difference between the real weight of the stone and its weight when submerged, proving that ARCHIMEDES was right.

If a body *floats* in a liquid, it means simply that the buoyant force is equal to the weight of the body, and that the body sinks in the liquid up to the point where it pushes aside an amount of liquid equal in weight to itself. You can verify this by weighing an empty, closed bottle and the water it causes to overflow from a filled vessel when carefully made to float in it, similar to the last experiment. The two weights are found to be equal in this instance.

A body can float only if its density (page 15) is less than that of the liquid in which it is placed. Wood, cork, ice and oil float on water because their densities are smaller; iron, stone and mercury sink. In the early days, the proposal to build ships of iron was ridiculed, because everybody knew that "iron is heavier than water." Actually, the *average* density of a steel ship (its total weight divided by its total bulk) is less than that of water because of its hollow and largely empty interior. As a result, it floats. The total weight of a ship is called its **displacement** simply because the weight is equal to that of the water displaced; and you can calculate the weight in pounds of a ship by estimating the number of cubic feet of it below the water line and multiplying the result by 62.5, the density of water expressed in pounds per cubic foot.

A fresh egg does not float in water; but dissolve a tablespoonful of salt in three-quarters of a glassful of water and even the best egg will float in it, because you have made the density of the liquid greater than that of the egg by adding salt.

A submarine can be made to descend or to rise by pumping water into or out of its ballast tanks. The effect is merely to make its average density greater or less than that of the surrounding water. Here's how to make a submarine that can be controlled with the touch of a finger: Get a glass jar with a flexible metal screw top, and pour in water right to the brim. Fill a small glass vial about two-thirds full of water, close the end with your thumb, and invert it into the jar. Adjust the amount of water in the vial very carefully, drop by drop, until it just floats. At this stage the slightest downward push should send it to the bottom momentarily. Now, with the jar full, screw the cap on tightly and the apparatus



Descartes' diver

is ready. Push down on the cover with your thumb and the vial hurries to the bottom and stays there as long as pressure is applied; release the pressure and it comes to the top. If necessary, readjust the amount of water in the vial until it works properly. The explanation? Pressure applied to the jar

cover is transmitted to the water, forcing slightly more water into the vial. Its average density is then just greater than that of water, and it sinks. On releasing the pressure, the air remaining in the vial pushes the extra water out again and the vial floats to the surface. This fore-runner of the submarine was invented by the French philosopher DESCARTES about three hundred years ago.

An old sailors' superstition says that when a ship sinks, it does not go all the way to the bottom but remains suspended somewhere in the lower reaches of Davy Jones' locker. Scientifically, this is false. When enough water has entered the hull to make the whole ship heavier than water, it keeps sinking until it hits the bottom; for if its average density is greater than that of water at the surface, it must continue to be greater even at the bottom, because we saw that water is practically incompressible.

A rock weighing a few pounds is placed in a pie tin, which floats in a dishpan of water. If the rock is thrown overboard, will the level of the water in the dishpan rise, fall or remain the same? Try it. Bear in mind that the density of the rock is perhaps two and a half times as great as that of water.

Since a floating body descends until it has displaced its own weight of liquid, the depth to which a floating object immerses itself is a measure of the density of the liquid in question. That's the principle of the **hydrometer**, commonly used to measure the density of the acid solution in the battery of your car. (The density in turn is a convenient measure of how fully the battery is charged.) A simple hydrometer is made by sticking two or three thumb tacks into the end of a wooden pencil, so that it floats in an upright position. Float it in water in a milk bottle or jar and mark the level of the surface of the water on the pencil. Then replace the water by a rather

concentrated salt solution and notice that the pencil rides higher than before. In oil or gasoline it sinks lower.

By noting its position when floated in two liquids of known density, a scale can be marked on the instrument, after which it can be used to read directly the density of any liquid into which it is put.

There's an old joke that goes, "Which burns longer, a thick candle or a thin one?" and the expected answer is, "Neither; all candles burn shorter!" This is not always true, and here's how to prove it: Stick a nail into the bottom of a lighted candle so that it floats upright in water. As the candle burns, the part above water will become longer and longer, because the candle becomes lighter and so rides higher.

3

NOW, TAKE THE AIR

You and I live at the bottom of a great, unbounded ocean—the atmosphere. When we are not moving and when no winds blow we are hardly conscious of its existence—yet it is all about us, producing remarkable effects.

One important fact about the air is that, like the real ocean, it exerts pressure on anything immersed in it. Down here at the earth's surface, the pressure amounts to a little less than 15 pounds per square inch—over a ton to the square foot. The only reason you don't feel this pressure is that it is compensated by an equal pressure from within; for there is air within the body cavities as well as in the tissues and fluids, and this counterbalances the force from the outside.

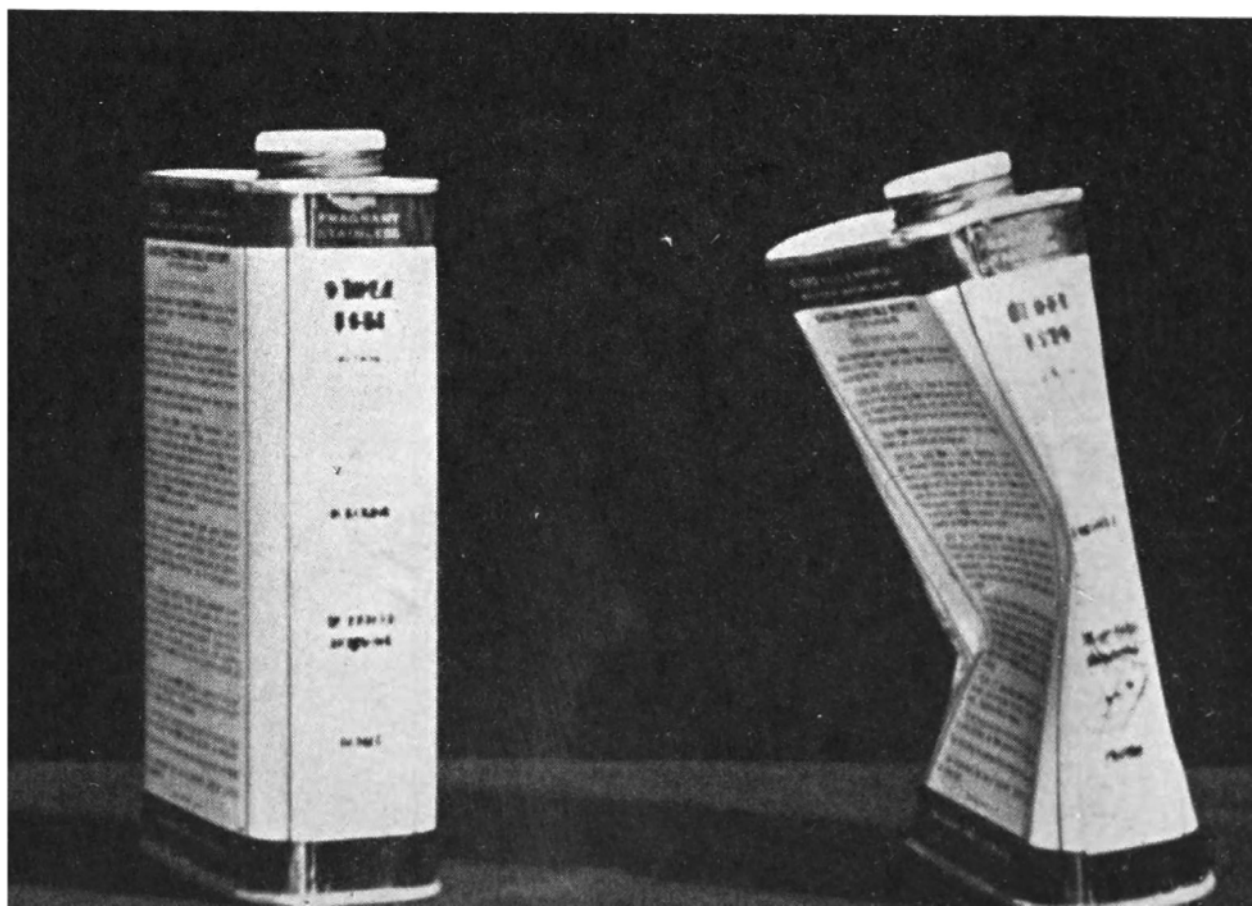
The existence of atmospheric pressure can be shown by removing the air from one side of an exposed surface. Secure a tin can that has a tightly-fitting cover or an opening provided with a screw cap. Place some water in the can, stand it in a pan of water and boil it vigorously with the cover removed in order to expel the air by means of the escaping steam. Weight the can down if it tends to upset. While the boiling is still in progress, close the vessel tightly, quickly place it in a sink and run cold water over it to condense the steam within. Outside air pressure does the rest (see photograph).

What makes the liquid rise in a soda straw? Is it "suction," as we commonly say, pulling the fluid up into your mouth? And if this is correct, how does the vacuum created by sucking get a grip on the liquid? The ancients evaded an exact

answer to such embarrassing questions by glibly prating, "Nature abhors a vacuum"—and that was that. If you had asked a gentleman of old Athens why the tin can in the last experiment became so dejected in appearance, he would have thrown this phrase back at you, implying that Nature simply hates to see a vacuum loitering about, and always acts to get rid of it. Of course you recognize at once that this is no explanation at all—at least not one that would satisfy a scientific-minded person today. But it sounded so definite and profound that it persisted for nearly two thousands years.

In the seventeenth century the Duke of Tuscany ordered a deep well dug. To his surprise, no pump was able to raise the water more than about 34 feet above the level in the well. When the perplexed noble asked the great GALILEO for an explanation he replied, undoubtedly with tongue in cheek, that "Nature's dislike for a vacuum evidently does not extend beyond 34 feet." But he did suggest to his friend and pupil,

Not "suction", but pressure of the outside air, collapsed the can





IL DIVINO GALILEO DIVINGENZIO GALILEI
PATRIZIO FIOR. FILOS. E MATEM.
DI FERDINANDO II. G. D. DI TOSCANA.
nato il dì XVIII Febb. MDLXII. morto il dì VIII Genn. MDCXLII.

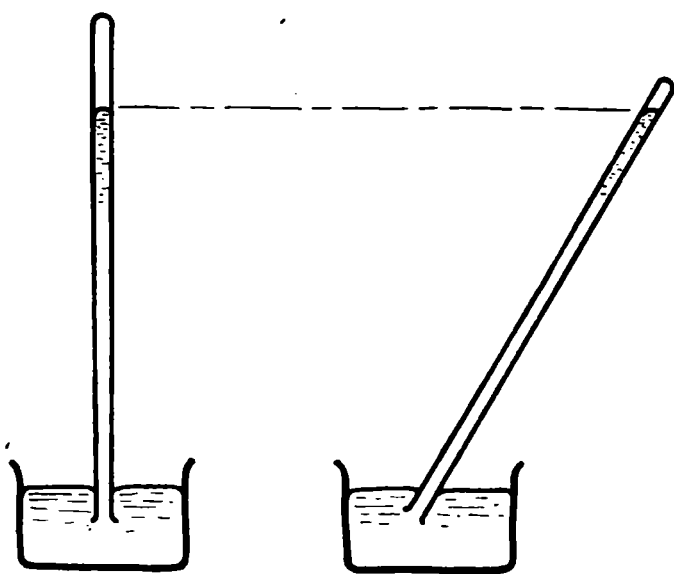


• Alla Propria Dottrina, ed Universal' Erudizione dell' Ill. Sig.
Dottore Tommaso Perelli Astronomo, e Matematico Celestissimo
Preside in Livorno in Tela di Sisto Subtermans appol. Ill. Sig. Gio. Battista Nelli
Fecit. Allegretti scul. 1611.

Courtesy G. P. Putnam's

Galileo Galilei, 1564-1642. He was the founder of
experimental science

TORRICELLI, that experiments be made to test "the power of a vacuum." TORRICELLI reasoned that if a column of water 34 feet higher was required to satisfy a vacuum, a much shorter column of mercury would be sufficient. Since mercury is about 13.6 times as dense as water, a height of only $34/13.6$ or $2\frac{1}{2}$ feet of mercury should suffice. And so he tried the following experiment: A yard long glass tube, sealed at one end, was completely filled with mercury. Holding the other end closed with the thumb, the tube was inverted and the open end immersed in a large dish of mercury. When the thumb was removed, the mercury in the upright tube fell away from the sealed end until its upper surface came to rest about 30 inches above the surface of the liquid in the dish. The mercury in receding from the top of the tube left a vacuum behind it, and it appeared that this vacuum was capable of holding up only a 30 inch column of mercury. TORRICELLI correctly concluded that the liquid is supported not by any mysterious sucking action of the vacuum, but by the *pressure* of the outside air acting on the surface of the



Inclining a barometer does not change the mercury level

mercury in the open dish. This pressure, transmitted to the liquid in the tube, is what really holds it up.

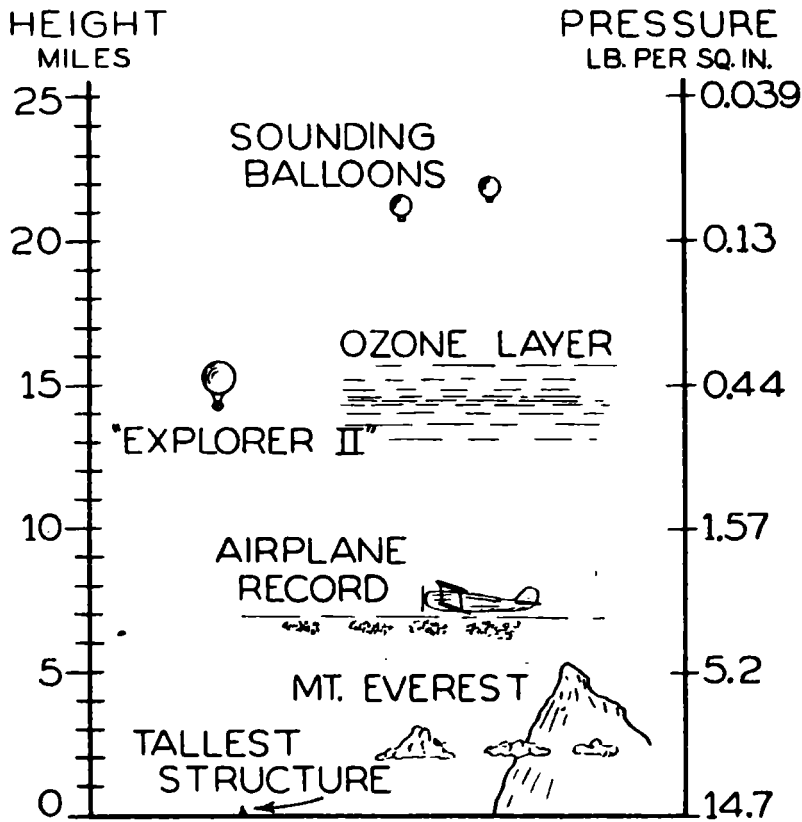
To complete the argument, others carried such instruments to the tops of mountains where air pressure is less, and truly enough observed that the mercury in the tube sank lower as they ascended but regained its former height upon returning to the plain. Here, then, was an instrument that could be used to measure changes in air pressure.

The exact way in which air pressure changes with altitude is known, so that your elevation above sea level when climbing a mountain or flying in a plane can be told simply by reading the barometer. For such purposes even a mercury barometer is too clumsy, so a special compact kind called an **aneroid** barometer is used. It is merely a metal can from which most of the air has been pumped. Changes in the outside air pressure cause the flexible cover to bend slightly (but not as drastically as the can that was made to collapse) and the motion is magnified by a pointer which can be arranged to indicate altitude directly. Of course, when the instrument is made, the scale must be compared with a standard mercury barometer.

The drawing shows pressures at various elevations in the atmosphere. Notice that the pressure declines rapidly with height. At the top of the Empire State Building the pressure is 4 per cent less than at street level. Winds and storms are confined to the region below about 7 miles—the **troposphere**. Above this is the **stratosphere**, a vast cold region of perfect calm where nothing ever happens except the occasional flash of a meteor or the shimmering glow of the polar light.

At about the time of TORRICELLI's inspired experiment, the versatile mayor of the German city of Magdeburg, OTTO VON GUERICKE, constructed a water barometer. But like the

man who built a motor boat in his basement, only to find he couldn't get it out the door after it was finished, GUERICKE found that his house was less than 34 feet tall. There was nothing to do but let the top of the tube project through a hole in the roof. A wooden figure floating on the surface of the water in the tube appeared above the housetop in good



Our atmosphere

weather, but retreated into the attic when a storm threatened. The good townsfolk were certain that GUERICKE and the Devil were working hand in hand.

A water column less than 34 feet high will not fall away from the top of a closed tube at all. Fill a tumbler brim full, slide a thick card across the rim to cover it completely, and turn the glass upside down. The card remains supported

and no water runs out. Water can flow out only if air enters. The purpose of the card is to prevent the water and air from flowing past each other in the wide opening.

It was this same ingenious GUERICKE who invented the first air pump and demonstrated the pressure of air by constructing two large iron half-spheres fitting together snugly at the edge. When the air was pumped out, two teams of horses were unable to pull the shells apart, but as soon as air was allowed to enter, they fell apart of their own accord. The small rubber suction cups used nowadays for temporarily fastening objects to a wall operate on the same principle. Moistening the cup makes an air-tight seal to prevent air from entering. When a pull is applied to the center of the cup the pressure within is reduced, making it hold fast to the surface.

Stand a heavy book on the table and attempt to blow it over with a single breath. If you succeed at all, it will be at the expense of much effort, for the impact of the air propelled by your lungs is hardly sufficient. Instead of using the *motion* of air, use the *pressure* built up by confining it. Place a paper bag under the book, allowing the open end to project out over the table edge. Gather the open end together between your fingers, blow into the bag and the book will overturn as the bag inflates.

Pack a piece of lightly crumpled tissue paper into the bottom half of a tumbler. Pour about half an inch of water into a dish. Now apply a match to the paper in the glass and quickly invert it into the dish. As the burning of the paper uses up the oxygen of the contained air, the pressure inside the tumbler is reduced and normal outside air pressure forces some water in.

Air is indispensable to all breathing creatures, but even if

we could live without it, the world would seem very strange in its absence. The blazing, blue-white sun would shine in a pitch-black sky and all the stars would be visible during the day. There would be no gradual twilight. Meteors dashing in upon our planet unhindered would be dangerous missiles. There would be no clouds, no storms, no sounds. It would be a strange, dead world indeed.

4

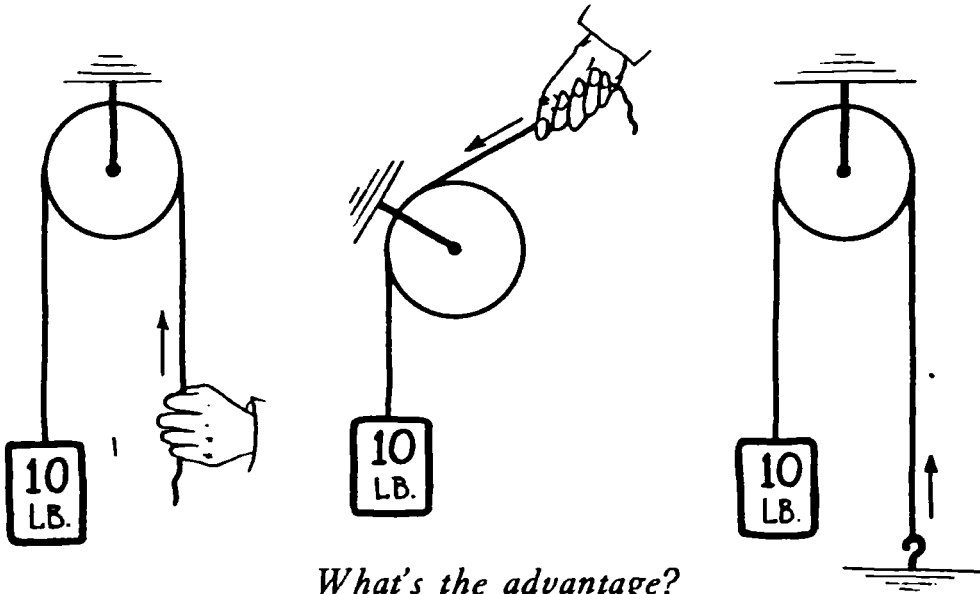
MECHANISM

EVERY day, whether we stop to reflect on it or not, all of us make countless mechanical experiments. Whenever you walk across a room, open a door, or lift a weight you put to use previously acquired experience and judgment of distance, force and balance—judgment that you've been acquiring since early childhood. All of this is within the province of mechanics, the science of weights and forces, of momentum and energy and power.

To begin with, consider what we mean by a **force**. It is perfectly correct to say that a force is a push or a pull, but how do you measure the *amount* of push or pull? Well, suppose you have a ten pound weight resting on a table. Then it is certainly reasonable to say that the weight is exerting a downward force of 10 pounds on the table top. That means that we can exert measurable forces, at least downward ones, by means of weights. But how about forces in other directions, say upward or sidewise? We can still do this by means of weights if we use some extra apparatus, such as a string and pulley. The pictures show how this is done. As long as the pulley is perfectly free to turn, the full amount of the weight acts. Pulleys enable a weight to exert its force "around corners," so to speak.

Now figure this out: Two 10 pound weights are tied to the ends of a cord which is hung over a pulley. The whole arrangement is naturally in balance. Now imagine one weight removed and the end of the string held instead by your hand,

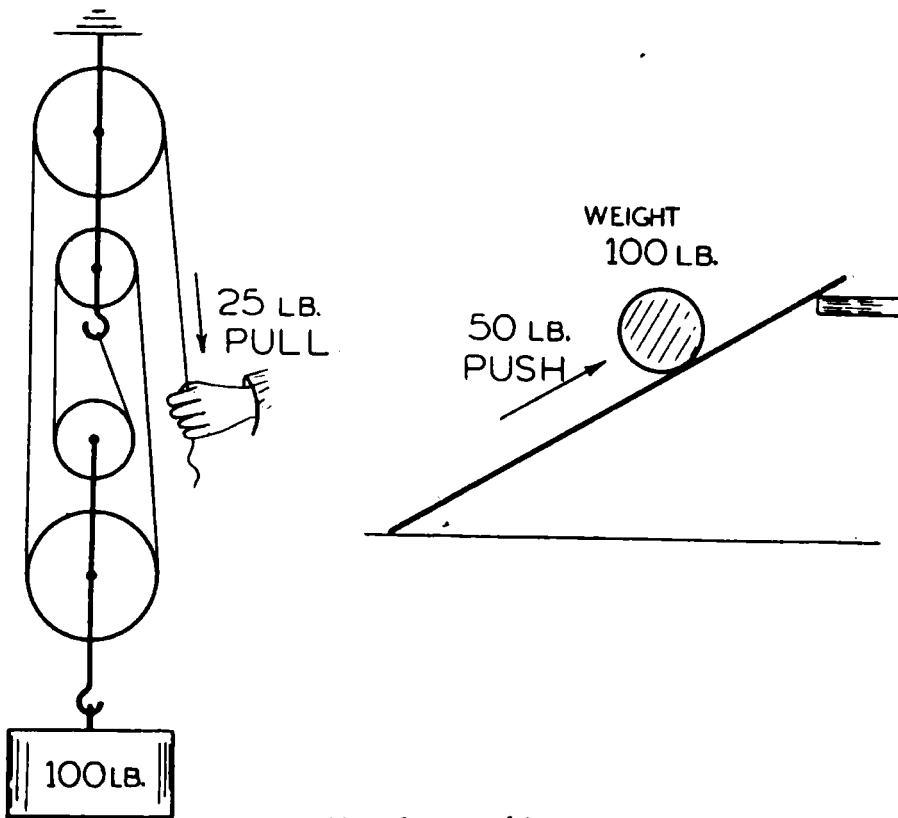
as in the first figure in the diagram. You already know that the hand must exert a downward pull of 10 pounds to hold the other weight still. Suppose you tire of holding the weight and decide to tie the end of the string to a convenient hook fastened to the floor. How great is the pull on the hook? Ten pounds is right. But contrary to what you might expect,



the downward force acting on the pulley is 20 pounds in this case, neglecting the weight of the string. You see, the pulley is acted upon by two downward forces,—the 10 pound weight and the 10 pound pull of the string tied to the floor (you can't have one without the other). Therefore, the total downward force on the hook in the ceiling must be 20 pounds. The force on the pulley-hanger shown in the second set-up in the diagram is less than 20 pounds, because the weight and the hand are not pulling directly opposite to the hanger. If a spring scale is available, you can set up these experiments and convince yourself.

In the third arrangement, the pulley is acted upon by two downward forces of 10 pounds each and one upward force—

the pull exerted by the ceiling hook—of 20 pounds. It's a general fact that when any object is in balance, the sum of the upward forces must equal the sum of the downward forces, and if there are any sideward forces, these must be similarly compensated. This principle is at the very heart of the design of skyscrapers and bridges.



Simple machines

Systems of pulleys can be rigged up to make it possible to apply much greater forces than you could otherwise exert. The familiar **block and tackle** is an example. The arrangement shown here is said to have a **mechanical advantage** of four, since a given force will lift a weight four times as great. But there's a catch to it, in a certain sense; for while you are able to exert four times as much force, your hand must move four times as *far* as the weight is raised. That's the way



inventor, whose name is associated with the principle of the lever was famous for his many mechanical inventions which to him were mere "diversions of geometry at play" —

**"GIVE ME A PLACE TO STAND
AND I WILL MOVE THE EARTH"**

Courtesy Kaufmann-Fabry

Nature prevents you from getting something for nothing. Nevertheless, a block and tackle is a useful device, for it enables you to lift loads impossible to handle without mechanical aid.

Another simple mechanical device with which everyone is familiar is the **lever**. A lever is any pivoted rod. One common example is the crowbar. To use it with greatest effect, place the pivot as close to the load as possible and apply the force as far from this point as you can. The mechanical advantage is then very high. ARCHIMEDES, discovering the principle of the lever in the third century B.C., was so impressed by the potentialities of this device that he proclaimed, "Give me a place to stand, and I will move the earth!"

All you need in order to rediscover the principle of the lever is a ruler, a pencil and several equal coins or other small weights. Balance the ruler, at its middle, across a flat-sided pencil. Place a stack of 6 weights with its center exactly over

the 4 inch mark of the ruler and you will find that 4 weights placed at the 9 inch point or 3 weights at the 10 inch mark will just balance them. In every case where a balance can be obtained, it will be found that the number of weights on one side multiplied by their distance from the pivot must equal the number of weights on the other side times their distance from the pivot. In the previous case, the stack of 6 was 2 inches from the pivot. The product is 12; and this is equivalent to 4 weights 3 inches away, or to 3 weights 4 inches away.

Or try another case: Place 5 weights 5 inches to the right of the pivot and 5 weights 3 inches on the other side. You'll find that they do not balance, but by adding 2 weights at a point 5 inches to the left of the center, balance will be restored. This set-up obeys the rule just stated, for $5 \times 5 = 5 \times 3 + 2 \times 5$. Notice, too, that 5 weights on one side are capable of balancing 7 on the other. It is not the amount of weight alone, but also its *distribution* which determines the balance.

And now for a further demonstration place a hammer on the table with only a short length of the handle projecting over the edge. Tie a cord to this end, and you will find it possible to suspend a rather heavy chair from the cord without tipping the hammer.

Other examples of the lever are scissors, nutcracker, derick, pliers, pump handle, fruit juice extractor, etc. Notice how many of the devices you use daily involve levers. In all cases the principle is the same. For any lever, as for the block and tackle, what is gained in force is paid for in increased distance to be moved.

Even simpler than the lever or the block and tackle is the **inclined plane**—merely a sloping plank. If you wish to lift a heavy keg from the ground and place it in a wagon, using

the least possible force, a good way would be to *roll* it up an inclined board. Then you would find that the keg could be pushed up the slope with a force much smaller than its own weight. In fact, if the height of the end of the plank is equal to half its length, the push or pull required will be only half the weight of the keg. This case is shown in the figure on page 41. By making the plank rather long, the force can be reduced considerably. But notice here again that while you are able to accomplish the result with a smaller force, you must move it through a correspondingly greater distance. There's no getting around it!

Borrow a child's wheeled toy or roller skate for the next experiment. Tie one end of a rubber band to the toy and keep it stationary on a smooth inclined board by holding the other end of the band. Tip the board at various angles to verify the fact that the steeper the incline, the greater the stretch of the rubber—that is, the greater the force needed to hold the car still or to pull it very slowly up the slope. This force varies from nothing at all, when the board is horizontal, to the full amount of the weight when the board is straight up.

The very useful inclined plane can be put in more compact form by literally wrapping it around a rod. Then we have nothing more nor less than a **screw thread**. Same principle, but friction is usually more troublesome here. Sometimes the screw is combined with the lever, as in a common form of automobile jack. Another form of inclined plane is the **wedge**, used for splitting logs or raising weights short distances.

So far we have seen how simple mechanisms can multiply force; now let's see how they can be turned around to multiply speed at the expense of force. By pinching apple or orange seeds between moistened thumb and forefinger you

can make them shoot several yards. Observe that the apple seeds invariably go farther. Knowing the wedge principle and the fact that the sides of the apple seed make a smaller angle than those of the orange seed, you'll probably be able to explain this fact.

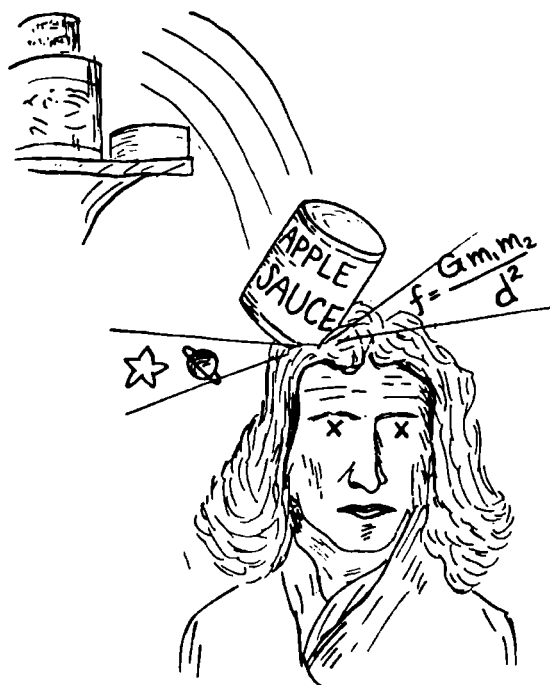
To make an effective table-top catapult, lay a ruler or slat across a stick so that the pivot point (the stick) is much nearer one end of the rule. Place a rubber eraser on the long end of the ruler and bring your fist down sharply on the short end. It will be obvious that the eraser goes up faster than your fist goes down.

And there you have very briefly the principles of mechanism upon which our whole industrial civilization is based. The complicated engines and machines of industry and commerce are but ingenious combinations of the pulleys, wedges, cams and levers with which we became acquainted in the preceding pages.

5

MATTERS OF GRAVITY

WHEN gravity is mentioned, most people think at once of the story of ISAAC NEWTON and the falling apple, but that story is probably more like the sauce than the whole fruit! For NEWTON's discovery of the Law of Gravitation, while undoubtedly a flash of genius, had a background supplied



Newton and gravitation

by much diligent labor and thought on the part of other men. The story is something like this: Since ancient times, it was believed that our earth was the center of the universe—that stars, sun, moon and the planets circled around a fixed, immovable earth. It was a natural way of thinking, for this

is exactly how it seems to be if you watch the sky for any period of time. What is more, people were so naive in the old days that they could not see how it could be otherwise;—the earth, the abode of man, *had* to be the center of the universe.

But certain bold thinkers were not satisfied. They looked at the question more deeply and the more they looked, the more difficulties they found with the old viewpoint. However, it was not until about the time of Henry the Eighth—almost the middle of the sixteenth century—that anyone did anything definite about it. It was then that the Polish astronomer NICHOLAS COPERNICUS dared to advance the notion that the *sun*, not the earth, was the pivot around which all the planets wheel. He was led to propose this idea because it enabled him to explain in a simple way the observed motions of the planets; but philosophers, theologians and other non-scientific people were aghast at this radical notion. COPERNICUS became very unpopular, and died a disappointed man.

At about this time, a German astronomer, JOHANN KEPLER, heard about COPERNICUS' idea and began to play with it. "I wonder," he asked himself, "if we can find any rhyme or reason to the motions of the planets if we adopt this new idea." Having at his disposal the thousands and thousands of accurate observations of planet positions made by his illustrious teacher, TYCHO BRAHE of Copenhagen, KEPLER set to work with paper and pencil to see what he could find, to search for law and order in this bewildering maze of numbers and angles. It was nearly a quarter of a century before he solved the problem fully, but solve it he did! And if you could have asked him why he devoted so much time and effort to a question that had absolutely no effect on the

daily lives of most people, he probably would have given much the same answer that our great researchers give today: "We can't help ourselves; it's an inner compulsion to know and to understand that must be obeyed."

What KEPLER found was a simple mathematical description of how the planets move. All the observed positions fitted in perfectly—a triumph of KEPLER's patience and ingenuity, and a belated victory for COPERNICUS too. But don't think for an instant that the Copernican view was even now accepted. It met only coldness and hostility. Meanwhile, the venerable Italian scientist GALILEO had constructed the first crude astronomical telescope. With his own eyes he obtained undeniable evidence of the fact that the planets revolve about the sun, yet he was forced by the terror-stricken authorities to stifle these ideas within himself and to make public denial of their truth.

ISAAC NEWTON was born the same year that GALILEO died. As a young man, he became interested in mathematics and physics. Soon he was puzzling over astronomical problems. He studied KEPLER's laws, wondered why Nature made the planets obey these particular rules and not some others. Was there anything deeper, more significant, behind these cryptic formulas? Now NEWTON did not solve his problem by dreaming idly beneath an apple tree; instead, he took up a lengthy calculation of the motion of the moon. Before long, he found that the moon's revolution around the earth could be perfectly explained if only he made the assumption that the moon and the earth *attract* each other with a force of a certain amount. Then the great victory: Starting with this very assumption, KEPLER's Laws could be deduced by a straightforward mathematical calculation—laws that it took KEPLER many years to find by trial and error. And so NEWTON found



Underwood & Underwood

*Isaac Newton, 1642-1727. The fruits of his insight will live
for all time*

that a force of attraction acts not only between earth and moon but between the sun and all the planets, keeping them in their appointed paths around the central orb. The theory of COPERNICUS was at last vindicated, and in a most elegant and convincing way.

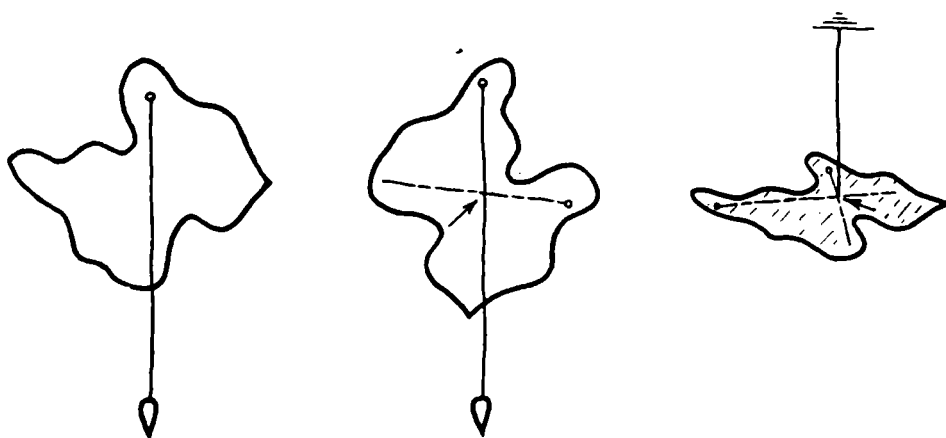
NEWTON obtained a formula stating exactly how this **gravitational force** between any two objects depends on the particular circumstances, but it remained for the ascetic English scientist HENRY CAVENDISH to make an actual measurement of the force of attraction between two bodies of ordinary size. This he did with an exceedingly sensitive form of balance. The force pulling the moon and the earth toward each other amounts to fifteen million billion tons. CAVENDISH used weights of a few pounds placed a few inches apart. Here the attractive force was of the order of a billionth of an ounce—about equal to the weight of ink in the period at the end of this sentence.

Let it be said that neither NEWTON nor anyone since his time succeeded in giving adequate explanation of what gravitation really is. But then do we know what anything *really is*—for example, electricity, or life? We find out a good many things about their behavior, but the question of their ultimate nature is one the scientist gladly leaves to the philosopher.

A particular case of gravitation is the attraction of the earth for objects on or near its surface. Then we speak of the force of **gravity**. This is really nothing but what we call the **weight** of the body in question. What we term a one pound weight is a piece of matter that, placed at a standard location, is attracted by the whole earth with a force of one pound. But lift this same weight to a height of 4000 miles above the earth's surface and it would "weigh" only a quarter of a pound. At the moon's distance, the earth's attraction for it would be less than half a hundredth of an ounce.

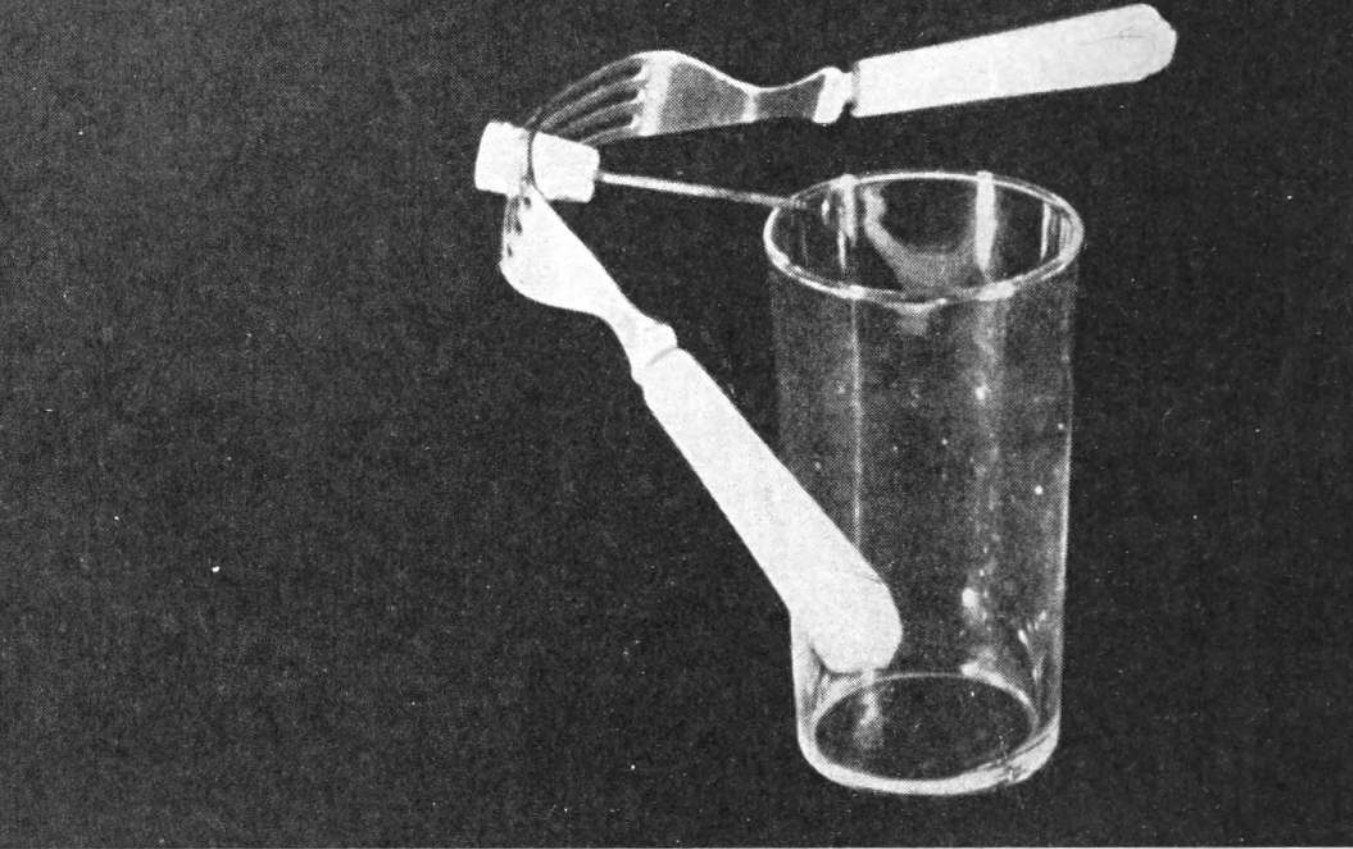
The gravitational attraction between any two bodies diminishes very rapidly if their distance apart is increased. If the distance is doubled, the force falls to $1/4$ of its former value; if trebled, it becomes $1/9$, and so on.

Gravity holds the oceans, the atmosphere and everything on earth close to the surface of the globe. It makes unsupported objects fall, urging them as near to the center of the earth as possible. Whether a supported object will stand up or fall over depends on the position of what is called its **center of gravity**. This is the place where the whole weight of the body can be considered concentrated. It is a mere point, a location, and sometimes it is inside the object, sometimes not. For example, the center of gravity of a yardstick is within it, at the middle, while that of a finger ring is at the center of the circle, and so is not inside the material itself.



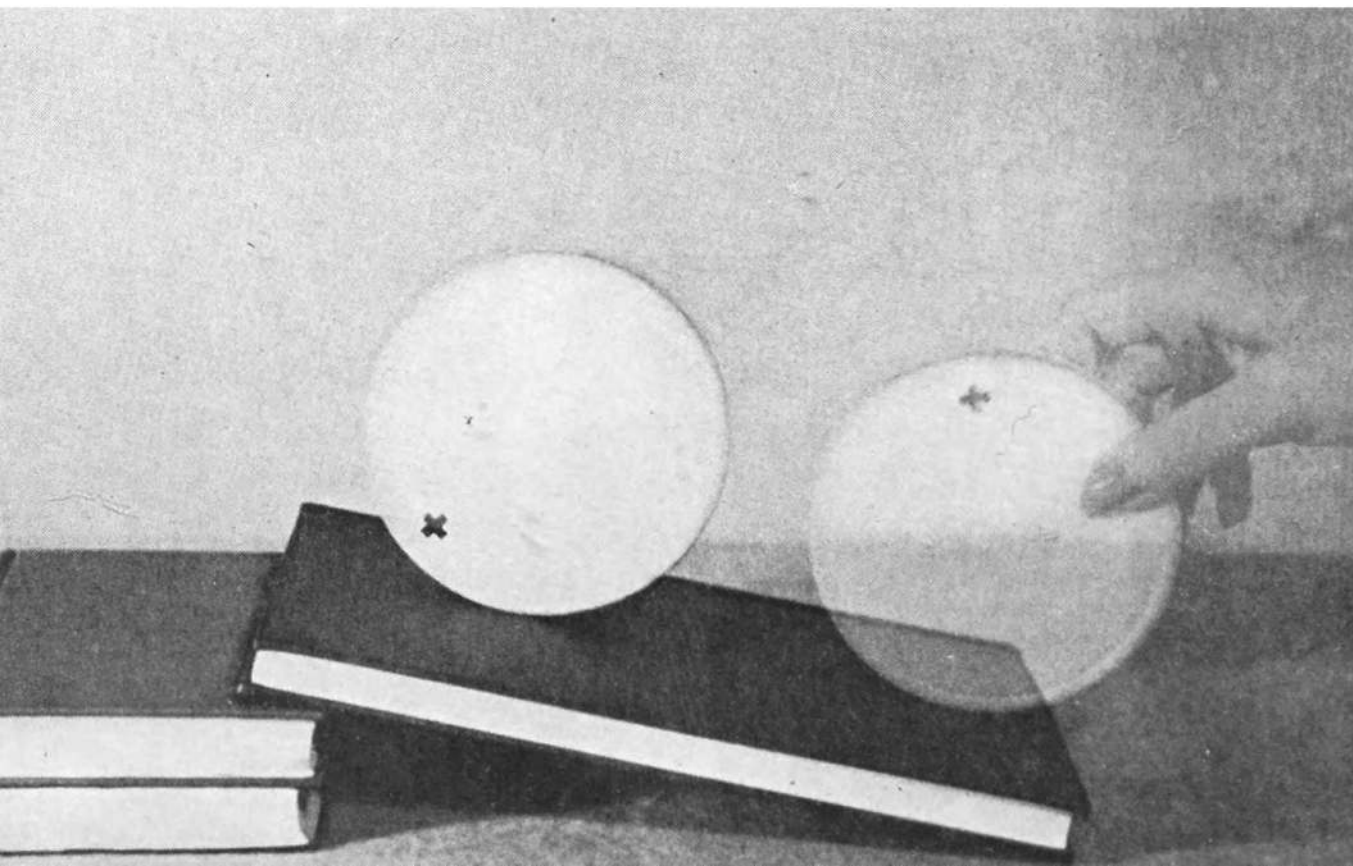
Finding the center of gravity

The interesting fact about the center of gravity is that if the body is supported at this point, it will “stay put” in any position. Here’s a way to locate this point by experiment: Cut out an irregular piece of sheet metal or heavy cardboard. Make a small hole at any point near the edge and hang the sheet from a smooth wall by means of a pin or nail passing freely through this hole. Hang also a plumb-bob (a thread



The position of the center of gravity makes this balancing feat possible .

The box rolls uphill, but its center of gravity goes down



with a small weight tied to it) from the nail and carefully mark the position of the thread on the sheet. Repeat the operation, using a different point near the edge. The place where the two lines cross is the center of gravity of the sheet, and you can satisfy yourself about the claim made for it by standing it on a tack or hanging it from a thread applied there and noting that it remains in any position in which it is placed.

Can you balance a pencil on its point, or a nail on the edge of a glass? Your failure is due to the fact that it is impossible to keep the center of gravity of the object vertically above the point of support, but that's something easily remedied. Thrust the point of a nail into a cork, stick a fork into each side, and now it is easy to balance the nail and all that goes with it, because the addition of the forks has brought the center of gravity of the entire arrangement well below the point of support. A comic variation is to replace the nail by two needles stuck into the bottom of the cork about half an inch apart. Set the device on a slightly sloping ruler or slat and push sidewise on the handle of one fork. The toy will waddle stiff-leggedly down the incline.

A pencil or a nail is said to be **unstable** when stood on its point, but it is **stable** when stood on its other end. A round pencil placed on its side on a flat table top represents **neutral** equilibrium—if given a slight push, it neither tends to move farther nor return.

Stable equilibrium is the most interesting case of all. In order for an object to be stable, its center of gravity must be vertically above the base on which it stands. Take the case of the human body. In order for you to stand unsupported, your center of gravity, which is midway between the hip bones when the body is straight, must be directly above the area

enclosed by your feet. Stand with your back against a wall, head and heels touching it. Drop a handkerchief on the floor about one foot in front of your toes and attempt to pick it up without bending your knees. Bending forward throws your center of gravity forward of your "base," making it impossible to stay erect. Just as instructive and even less dignified is the stunt of standing facing a wall, with your toes about two feet from it. Place your hands on the wall for support and lean forward until your head touches. Then, removing your hands from the wall, try to regain an erect position. If you're a man, no amount of headwork will help; a woman, however, may succeed, due to different weight distribution.

Every object tends to get into the position where its center of gravity is as low as possible. That's why the pencil fell over when we attempted to stand it on the point, or why a marble placed in a salad bowl always comes to rest at the lowest point. This is not always so obvious. Fasten together with a gummed paper or adhesive tape two rulers or strips of stiff cardboard to form a "V." Spread the arms of the "V" a few inches and rest the point on the table, the other ends on a thin book (the best height will be found by trial). Secure two identical tumblers with decidedly conical (not flat) sides and tape the open ends together to form a double cone. Now for the performance: Lay a round pencil or tin can across the arms of the "V" at the high end; as expected, it rolls down to the low end. But now place the double cone square across the rails at their *low* end, as in the picture, and watch it roll uphill! The spread of the "V" and its slope may have to be adjusted a bit before it works perfectly. How to explain it? Here's a clue. Measure carefully the height above the table of that all-important center of gravity of the double cone (same height as the central axis), first when the cone is at one end

of the runway and again at the other, and you'll see that the shape of the rolling object and the spread of the rails conspire to make it seem to go uphill while it really goes down.

Even more surprising to an onlooker is the behavior of a flat, round can or cheese-box. Beforehand, fix a small weight at one point of the rounded surface on the inner side, say a coin or large marble fastened in place with a bit of adhesive tape. Make an inconspicuous mark on the outside of the box at the position of the weight and replace the cover. If, now, the box is placed on an incline, with the weight slightly on the downhill side of the topmost point, it will roll down the slope as expected. But now—and here's the surprise—set the box on the slope near the bottom, this time with the hidden weight slightly on the uphill side of the vertical, and it will roll *up* the slope of its own accord, gathering speed as it goes and plunging over the top edge. Make certain the slope is not too long; otherwise it will stop near the top and rock back and forth, finally coming to rest on the incline. Here, as in the double-cone arrangement, the motion is apparently uphill. This is quite natural and allowable as long as the center of gravity descends in the process.

This chat on gravity may well end with a little imaginary experiment for you to ponder on. Think of a perfect steel ball placed near one edge of an absolutely smooth, flat, level table top. Assume that there is nothing to impede the free movement of the ball. Will it move or remain at rest? To answer this question, notice the curious fact that because of the earth's curvature, the middle of a flat, level table is really lower (that is, closer to the center of the earth) than its edge. For a table four feet across, the middle is about a millionth of an inch lower than the rim.

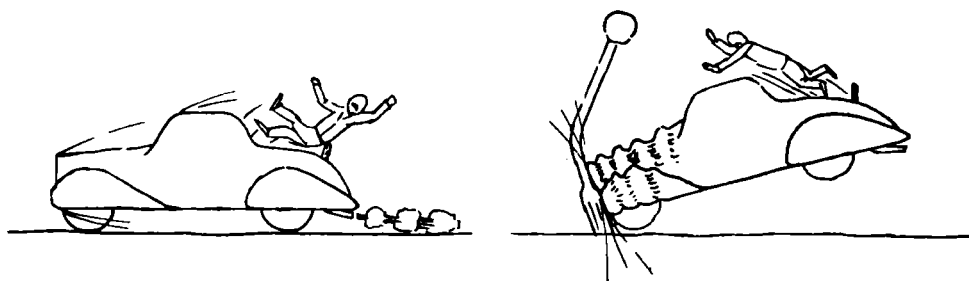
6

THIS DYNAMIC UNIVERSE

NOBODY doubts the fact that a sack of potatoes, a piano, a pail of water have weight—which means, as we now know, that these and all other material objects are attracted by the earth. But there's something more to this story. Matter not only resists our efforts to *lift* it, but shows a desire to stand still when we try to move it suddenly in *any* direction. You may find this out by painful experience if, falling a victim to Halloween pranksters, you kick a hat which proves to have a brick concealed beneath it.

It is not only bodies at rest that tend to stay "as is"; moving bodies behave in a similar way. They try to keep going serenely along, and if you want to make them go faster or slower you must use force. Assume that you are sitting in a stationary automobile. The traffic light turns green, and the driver starts the car rather briskly. As a result, you fall back in your seat. But has anything really shoved you backwards? Not at all; the apparent backward jerk was merely relative to the car. The sudden start tried to set you into forward motion, your body strove to stay where it was, and you really would have remained at rest had not the back of the seat unceremoniously shoved you into motion. Now, having gotten over this bad start, you are riding along on a smooth, straight road at a steady rate. You feel nothing, because there is no agent operating to change your state of motion. In fact, if there were no noise or vibration, no air rushing by, and if

If you were blindfolded you would be unable to tell whether you were moving at all—or if so, how fast. Finally, imagine the brakes suddenly applied to your vehicle. How to explain the fact that you pitch forward? Surely, the brakes do not exert their force directly on the passenger! The explanation



The consequences of sudden starts and stops

is of course that you tend to keep going as you were before the car stopped, and so with reference to the car you seem to spring forward.

This universal property of all things, whereby they tend to keep on in their state of rest or motion, was first clearly recognized by GALILEO. It is called **inertia**.

A wine glass, a playing card and a silver coin. No, this is not the set-up for a party, but for an interesting experiment to test the idea of inertia. Place the card on top of the glass and lay the coin centrally upon it. A snap of the finger will send the card sailing through space, but the coin remains and falls obediently into the glass. The short-lived force of friction between card and coin had no time to overcome the "as-is-ness" of the coin.

Another version of this is favored by vaudeville jugglers who remove the cloth from under a fully set dinner table by a deft jerk. Don't use your best set of china if you decide to try this stunt at home.

When workmen demolish a building, they usually start at the top, but here's a way to tear down a tower by beginning at the bottom. Set a stack of poker chips or identical coins on the table. By slicing at the bottom one with a knife, using a quick, sidewise stroke, one after another can be removed from the stack without disturbing the upper members. Inertia again.

Suspend a rock or other medium-sized weight from a door-knob or from a hook by means of a thread. Tie a two-foot length of the same kind of thread to the lower end of the weight. If you pull downward on the lower thread, will this one or the upper one break? Try it yourself before reading on to find out what "ought to" happen. A steady pull invariably breaks the upper thread, because it is subjected to the pull of your hand plus the weight of the rock, but you can make the lower thread break and leave the upper one whole by giving the former a sharp jerk in place of a steady pull. The inertia of the weight prevents it from moving far enough to sever the upper thread during the short time the jerk lasts.

GALILEO believed in experimenting. He set balls rolling on a level table and found that they really tended to keep going at a steady speed in the direction in which started. The smoother and flatter the table, the farther they went before stopping. Conceivably, if friction and resistance could be eliminated altogether, inertia would keep them going forever. Motion is just as natural as rest, and if you want to change a body's state of motion or rest you've got to apply forces. What is more, it takes a harder push to impart a given speed to a heavy body than to a light one—and it takes a greater force to stop the heavy one, too. A moving mass is said to have **kinetic energy**,—energy of motion. The amount

of energy is a measure of how much damage it would do if it crashed into a stationary object.

Pull a cart, and you find that as long as you continue to exert a given pull, the cart moves faster and faster—it **accelerates**, as we say. Apply a lustier pull, and it picks up speed at a greater rate. All of these things are known to us almost intuitively, yet it was not until NEWTON that the facts were stated in perfectly general terms, applicable to any mechanical situation. NEWTON's Laws of Motion are probably the greatest generalization in all of science. They make it possible to calculate the exact results of any mechanical problem.

One of the most interesting applications of mechanical laws is to the case of a freely falling object—say a stone released from an upper story window, or an apple falling from a tree. Exactly how does a falling body move? Do heavy things fall faster than light ones? Such were the questions that puzzled thinkers for centuries. “Of course,” you say, “everybody knows that heavy objects fall more rapidly than light ones. All you have to do is to drop a stone and a piece of paper at the same instant from the same height and there's no question that the stone hits the ground first.” While this may sound like good, common sense, it is misleading. The difference in behavior is not due to the difference in weight of the two things, but to the resistance which the air offers to their passage—much greater, of course, for the bit of paper than for the more compact stone.

In a vacuum—or for short distances in air—all objects, light or heavy, fall at the same rate. This the great GALILEO discovered three and a half centuries ago by dropping two iron balls of different weight from the famed Leaning Tower

at Pisa. His idea was that since both objects were fairly heavy, the usually disturbing resistance of the air could be ignored. A crowd of the master's students gathered to watch (this most famous science experiment in history drew about one thirtieth as many spectators as a present-day baseball game). The weights were released. The single "thud" of their simultaneous impact with the ground was exactly what GALILEO expected. To him, it was a death blow to the mistaken notion that heavier objects fall faster. The spectators slowly dispersed—uncomprehending, unconvinced.

Repeat GALILEO's experiment by dropping a cork and a stone at the same instant to verify that they strike the floor together.

Now that we know the all-important fact that all bodies fall at the same rate, let us look into the more detailed question of how a stone moves while rushing earthward. Does it begin to pick up speed as soon as it is released, or does it move at a constant rate? Try this: Drop a small object from a height of four feet. It reaches the floor in half a second. Repeat the experiment, standing on a table or ladder. The time taken for the fall, even now, is less than a whole second, although the distance covered is perhaps three times as great as before. This means that a falling body *picks up* speed as it falls, for if the motion were at a *constant rate*, it would take just three times as long to fall three times as far.

As a matter of fact, NEWTON's laws predict and accurate experiments verify the fact that a falling body moves with **constant acceleration**—that is, it picks up speed at a constant rate. Measurements show that the gain in speed of any falling object is at the rate of about 32 feet per second during each second of fall. This means simply that the stone is moving at

a speed of 32 feet per second 1 second after release, 64 feet per second at the end of 2 seconds, 96 feet per second after 3 seconds, etc. And, in a vacuum, the speed would continue to build up at this rate as long as the body continues to fall.

More important than the matter of speed is the question of how *far* a body drops in a given time. Since we saw that the speed of fall is ever increasing, the distances covered in successive seconds must also become greater and greater. To one end of a ten foot length of cord tie a small, inelastic weight, such as a potato. Fasten similar weights at the one-foot, four-foot and nine-foot points. Standing on a table or ladder, grasp the far end of the string letting the entire string hang freely at such height that the first weight is just a few inches off the floor. Now release the cord and observe that the sounds of the four impacts with the floor occur at perfectly regular time intervals. If unconvinced, try the same experiment this time with the weights *evenly* spaced along the string, and notice how the impacts come at shorter and shorter intervals. The first experiment shows that a body which falls a given distance in one unit of time, say a second, will fall not twice but 2×2 or 4 times as far in two units of time, and not three times but 3×3 or 9 times as far in three time units, etc.

If you have a stopwatch, or if gifted with the ability to count seconds accurately, you can use the laws of fall to find out the height of a house, cliff or tower by timing the fall of a stone released from the top. Merely multiplying the time, in seconds, by itself and multiply the result by 16 and you have the height in feet. For example, if a pebble dropped over a cliff takes $4\frac{1}{2}$ seconds to fall to the base, the height is $4\frac{1}{2} \times 4\frac{1}{2} \times 16$ or 324 feet.

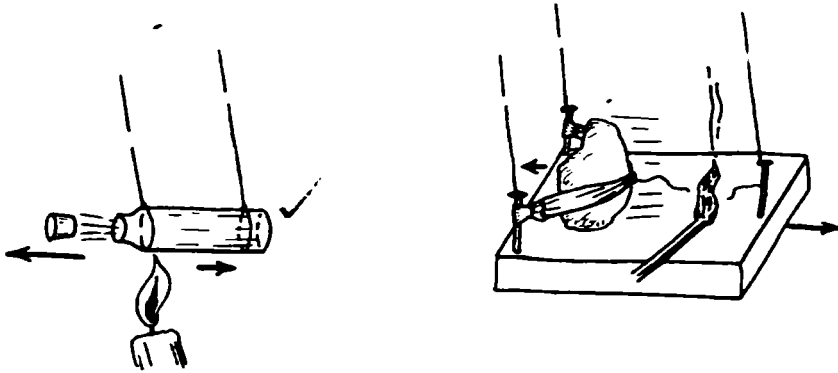
Here is a little data on falling bodies, calculated from the laws just discussed:

<i>Time after start</i>	<i>Downward speed at this time</i>	<i>Distance fallen from start</i>
0 sec.	0 ft. per sec.	0 ft.
$\frac{1}{2}$	16	4
1	32	16
2	64	64
3	96	144
4	128	256
5	160	400

Another aspect of NEWTON's work concerns what happens in collisions or in any similar case of a sudden or violent change of motion. When a bullet is fired from a gun, the gun itself experiences a backward "kick." In NEWTON's words, the **action** of the forward motion of the bullet is accompanied by an **equal, opposite reaction** on the part of the gun. The bullet leaves the gun, going forward at a certain speed. According to the principle of inertia, it would keep going forward at this speed in the original direction forever were it not for the retarding action of air and the pull of gravity swerving it down to earth. And similarly, the gun would continue to move backward with a constant but much smaller speed. There's a very simple relation between the two speeds: The weight of the bullet multiplied by its forward speed equals the weight of the gun multiplied by its speed of recoil. A similar reaction occurs when you jump from a rowboat to the river bank. The boat moves backward, but in this instance friction soon brings it to rest.

To demonstrate the kick of a gun, place a few drops of

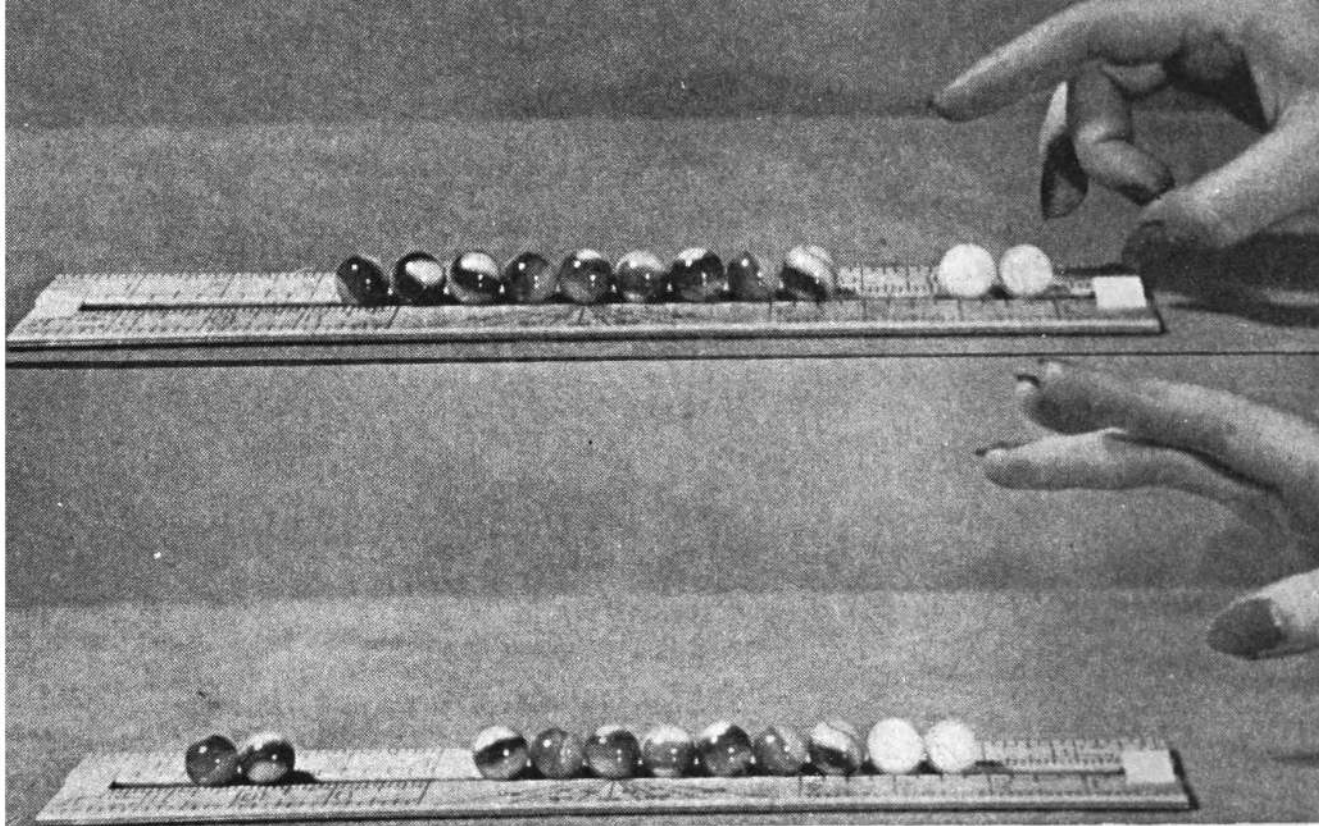
alcohol in a vial or small bottle and insert the cork, but not too tightly. Hang the vial horizontally by means of two parallel lengths of thread. Heat the vessel gently with a candle flame until the alcohol vapor pops the cork out, and



Recoil

observe the recoil of the suspended bottle. Another test of recoil can be carried out using a rubber strand sling-shot mounted on a board hung from threads. To release, burn the string that stretches the rubber band.

A yachtsman whose craft was often becalmed had the bright idea of mounting a powerful electric fan on his boat to blow air into the sails. He was puzzled no end to find that it didn't work, for he expected that the air set in motion by the propeller would deliver its momentum to the sail, and so propel the boat. Perfectly true, but he overlooked one thing: Since the air stream gets its motion from the fan, the latter must experience a backward reaction. Being attached to the boat, the fan transmits this backward effect to the whole craft, just offsetting the influence of the moving air hitting the sail. In fact, the power-driven fan would have propelled the boat backward if he had merely dispensed with the sail entirely, for isn't that exactly the way the propeller of a ship



Marbles striking a stationary row drive off an equal number from the end

or airplane works? Water, or air, is set into motion toward the rear; the reaction imparts forward motion to the craft.

The handing-on of motion in collisions may be shown by placing a row of several glass marbles in a groove formed by two rulers resting on a table. The marbles should touch each other. Now, with a flick of the finger, propel another marble toward the end of the row. When it strikes the others, none moves except the one marble at the far end, which springs forward with about the same speed as that with which the first one was propelled. Try shooting two marbles simultaneously, as in the pictures, or three. In each case, an equal number rebound.

If marbles are not available, the same experiment can be performed almost as well with nothing more than a few poker chips or identical coins. Lay them in a row, about half an inch apart, on a smooth table top or oilcloth. Use a ruler or the edge of a book to line them up perfectly straight. From

a somewhat greater distance, send one of the coins directly at the end of the row with a flick of the finger. Each coin will take the place of the next one as the motion is transmitted down the line, and the last coin will rebound to a greater distance. Repeat by projecting against the end of the row two coins in contact.

In every elastic impact, such as the bouncing of a ball, the object struck is first compressed by the blow; then, because of its elasticity, it strives to return to its original shape, producing the observed reaction.

Sober scientists have suggested that it might be interesting to shoot a rocket to the moon. A rocket, you know, gets its propulsive force all during its flight by means of gases ejected explosively in the backward direction. Granted that our moon rocket could carry enough fuel and the oxygen to burn it, would the reaction of the outstreaming gases be able to propel it even after it leaves the earth's atmosphere—after there is no longer any air to “push back against?”

7

AIR IN ACTION

LIQUIDS and gases at rest are interesting subjects for observation and experiment, but set them in motion and they become much more intriguing, more puzzling. Let's find out for ourselves the principles behind airplanes and atomizers, baseball curves and boomerangs—for all are dependent on the rapid motion of air.

First, we return to a topic of the last section—objects falling through the air. What we found there is strictly true only for rather heavy bodies or for short distances of fall, because it is only in such cases that the disturbing effects of air resistance can be ignored. In fact, if you repeat the test of dropping a cork and a stone (page 60), this time from a height of fifty feet or more, you'll find that the stone hits the ground a shade earlier.

Take a coin and a circular piece of paper slightly smaller in size—say a quarter and a paper disc the size of a nickel. If the two are released at the same instant, the bit of paper will of course fall more slowly than the coin. Now, hold the coin horizontally with thumb and forefinger at opposite edges, put the paper centrally upon it and let go. This time both drop at the same speed, staying together as they fall because the coin obligingly pushes the air aside for the paper disc.

Blow a few drops of liquid from an atomizer and notice that the larger drops fall faster. The same is true of raindrops, and a lucky thing it is that the air impedes their motion; otherwise, the ones that strike you during a shower would be

going something like 800 feet a second—ten times as fast as an express train—and it would be fatal to be like the mythical nitwit who doesn't know enough to come in out of the rain. Average-sized raindrops fall with a speed of only about 25 feet per second. The fact is that any object falling a considerable distance in air soon reaches a *constant* speed after a time, and this final speed depends mainly on the size and shape of the falling body. With a parachute to increase the resistance, a jumper reaches the earth at a safe speed; if the 'chute should fail to open, the unfortunate pilot would terminate his career at more than a hundred miles an hour.

Let us consider that airplane before the pilot "bailed out." What keeps it aloft? Is it the impact of air on the lower surface of the wings? True—but that's only a small part of the story. Aeronautical engineers measure the forces acting on airplanes by suspending small scale models in a chamber through which a propeller forces a powerful stream of air. Naturally, it makes no difference whether the plane moves through still air, or air blows against the stationary plane; it's the relative motion only that matters. Pictured here is the Full Scale Wind Tunnel of the U. S. National Advisory Committee for Aeronautics, in which a full-sized airplane can be tested. The air stream of this man-made hurricane is 60 feet across and 30 feet high and travels 118 miles an hour. It is produced by two huge propellers, each driven by a 4,000 horse-power electric motor. The plane to be studied is mounted on streamlined struts which rest on balances in the chamber below, so that the forces acting on the machine can be measured under actual flight conditions.

This tunnel is the only one of its kind in the world, but *you* can find out a thing or two about aerodynamics by experimenting with a two-lung-power wind tunnel. Cut a strip a



Courtesy National Advisory Committee for Aeronautics

Airplane ready for test in the full-scale wind tunnel

Air moving across the top surface holds up an airplane wing



little over an inch wide off the side of a postcard and give it the curved shape of an airplane wing-section by pulling it back and forth lengthwise over a table edge. Bend one end snugly around a pencil, support the strip for a moment and begin blowing along its *upper* surface. The fact that it remains supported shows that the top of the wing is responsible for at least part of the "lift." Now that you know this much, experiment with a free-flying airplane by cutting out the one on page 239. Fold it as indicated, and attach a small paper clip to the front to adjust the center of gravity so that the plane soars when launched with a slight forward push.

The fact that the wing was drawn *into* the stream of moving air instead of being pushed aside by it illustrates a general truth discovered by the eighteenth century Swiss scientist DANIEL BERNOULLI: A moving fluid—and that means either a liquid or a gas—exerts less sidewise pressure than one at rest. It explains the curving of a baseball or a "sliced" golf ball, the operation of an atomizer or the carburetor in your automobile, and a great many other things.

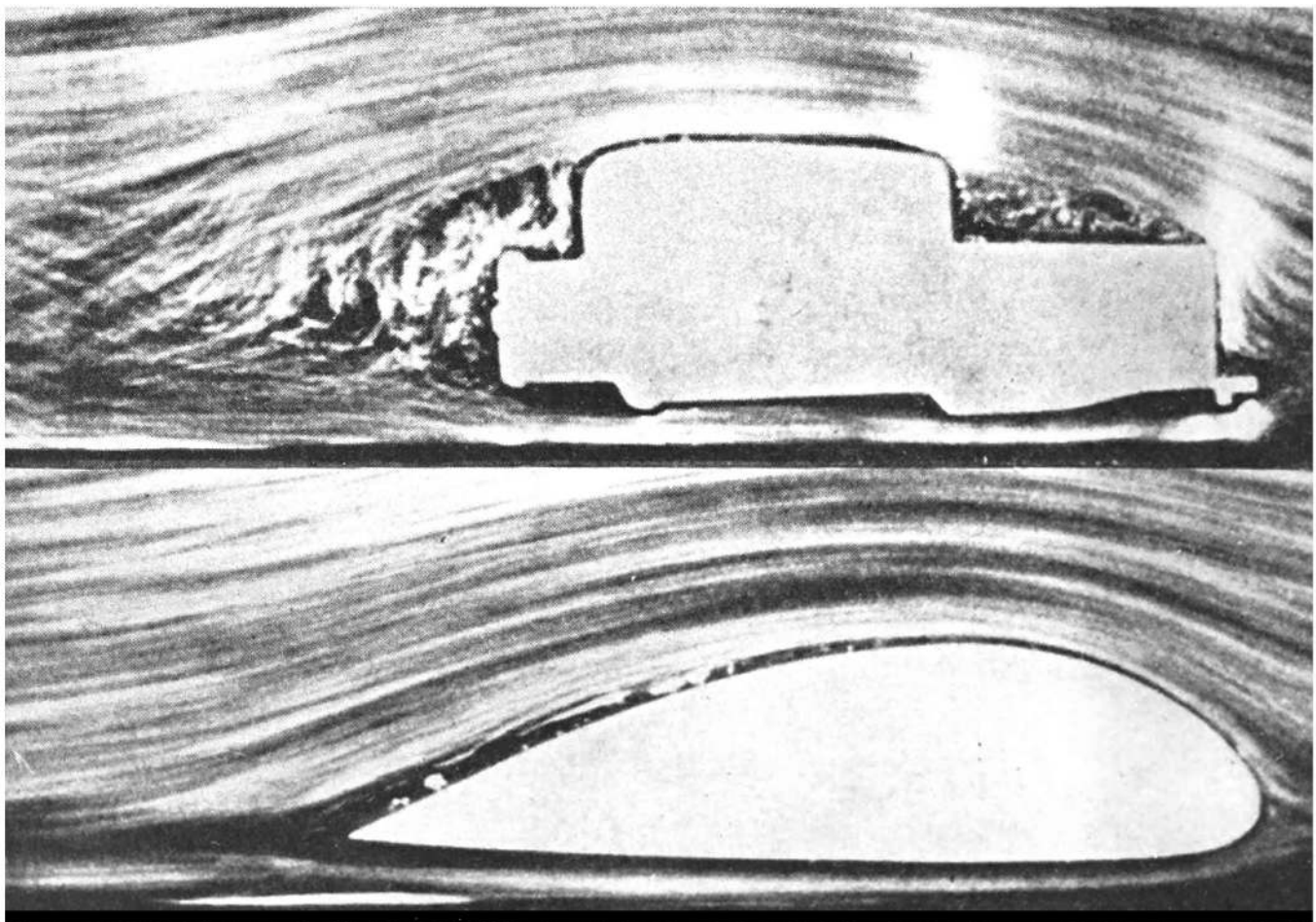
Thrust a pin through the center of a two-inch square piece of light card. Place the card flat upon one end of a spool with the pin projecting into the hole to prevent the card from slipping off sidewise. Blow through the spool from below as hard as you like, you'll not budge the card; in fact, the harder you blow, the tighter it sticks. Turn the whole arrangement upside down and the card can be supported in this way, as the picture shows. The explanation is that between the card and the flat top of the spool air is moving rapidly outward, while the air in contact with the outer surface of the card is at rest. According to BERNOULLI, the result is a force holding card and spool together. Not such a mystery after all—or is it?

Lay two slats or rulers parallel to each other, about half an



Blowing makes the card cling to the spool

Smooth air flow means low resistance to motion



inch apart, with their ends resting on two books so that they form a pair of level rails. Place two pingpong balls about an inch apart on the rails. With a soda straw, direct a stream of air downward between them. Can you tell why they come together rather than blow apart? The same sort of broadside collision may occur when two boats or cars pass each other closely at high speed.

Like most good things, moving air or water has its bad side—witness destructive windstorms, floods, tornadoes. To the airplane designer, the ship builder, the artillery expert, fluid resistance is a big problem, especially at high speeds. That's why we hear so much today about **streamlining**, giving the moving body smoother lines so that the fluid is less disturbed by its passage. The less disturbance in its wake, the easier it is to propel the object. Designers have so accustomed us to streamlined forms that we now prefer these shapes even for things like flat-irons and rolling pins that—in well-regulated households—are not meant to fly through the air.

A simple test will illustrate the power of the air to oppose rapid motion. Place a pencil or any piece of wood approximately the same size on a table, with about a quarter of its length extended over the edge. A sharp downward blow from a ruler or cane directed onto the projecting end will send the pencil flying, but will do it no harm. Now lay a single piece of letter paper over the part of the pencil that rests on the table and repeat. This time the pencil will be cut off clean, all because of the air resistance of a mere piece of paper.

Even automobiles are now being tested in wind tunnels to find out how to get more miles per gallon of fuel by cutting down air resistance. When you drive at 40 miles per hour, over half the engine power is being used to overcome air drag.

Contrary to general opinion, the way to reduce resistance is not by giving the body a sharply pointed front to “cut the air,” but by tapering its rear to minimize eddies in its wake. Nature found that out all by herself when she “designed” birds and fishes, and we are mere imitators with our airplanes, dirigibles, ocean liners and submarines.

8

GYRATION

ONE of the most satisfying things about science is that once you have unearthed a general principle, a multitude of happenings become understandable. Take, for instance, the idea of inertia. Far from having exhausted its possibilities for explaining Nature's ways, we're now going to use it to find out something about the behavior of things that spin or turn.

If a vehicle in which you are riding takes a sharp, unbanked curve, you at once become aware of a force seeming to push you toward the outside of the curve. A ball or an apple swung around in a circle on the end of a string appears to exert an outward pull, striving to get away. In either case, notice that the tendency to escape increases with the speed of motion and also with the abruptness of the curve. This outward urge is known as **centrifugal force**.

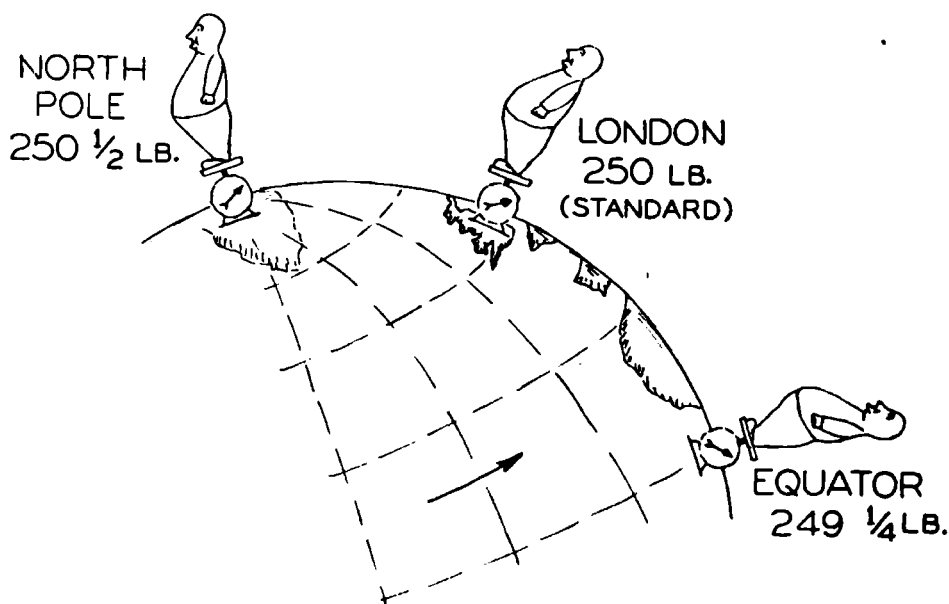
Centrifugal force is merely a manifestation of the inertia of the moving object. It would prefer to keep going in a straight line. Forced to move in a curve, it expresses its resentment by exerting an outward tug. The constraining force in the case of a car on a curve is the friction between tires and road; for the ball whirled in a circle, it is the pull of the string. As soon as the road straightens out or the string breaks, the centrifugal force vanishes, for it is merely the reaction of the constraining force, and is always equal and opposite to it.

Swing a ball or an apple in a vertical circle by means of a two-foot length of string. Let go of the cord at the instant the weight is moving directly upward. You might expect the

weight to fly out horizontally, straight away from the center; instead, it goes straight up, because inertia compels it to keep moving in the direction it was going at the moment it was released.

A glass partly full of water can, with care, be swung at arm's length in a vertical circle without spilling. Start with the arm straight down, glass held firmly behind the wrist on the upturned palm. Swing it forward and up overhead, making sure to clear all surrounding objects.

Centrifugal force is responsible for the fact that the earth and other planets, especially the giant Jupiter, bulge at the



Your weight depends on where you live as well as how you live

equator. While they were still in a plastic state, billions of years ago, their rotation probably operated to produce this effect. A point on the earth's equator is about thirteen miles farther from the center than is either pole. A further consequence of the earth's spin is that a body at the equator weighs a trifle less than it does at the poles, for two reasons: For a

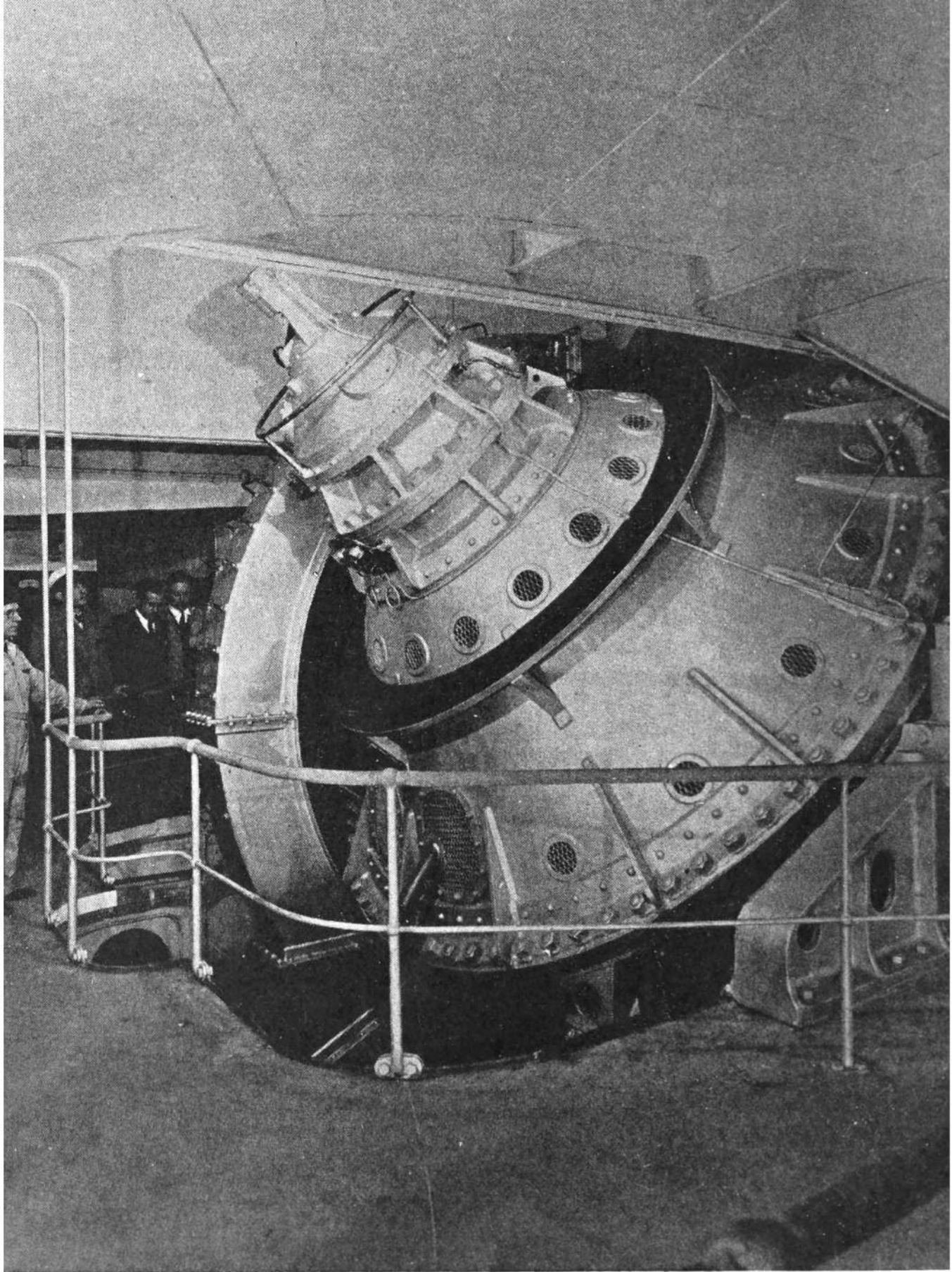
given rate of turning, the centrifugal force is greater for the object farther out; also, the actual gravitational attraction is less at the greater distance. If the earth were to rotate about seventeen times as fast as it does at present, things at the equator would just begin to fly off into space.

Float bits of cork or wood in a glass of water containing a few glass beads and stir the water rapidly. Observe that the beads go to the outer edge along the bottom, while the floating particles gather at the center. The explanation is that the heavier the particle, the greater the centrifugal force acting on it. Floating objects are of course "lighter" than water, the beads are "heavier." This is precisely the principle of the cream separator: Skim milk, which is denser than cream, goes to the outer edge of the vessel where it is drawn off.

In recent years centrifugal force has been a potent tool of biological researchers. Using ultra high-speed **centrifuges** producing enormous separating forces, they are tracking down some of the most elusive secrets of living matter.

It is a fact of experience that force must be exerted to set a grindstone or a revolving door spinning, and that once it is established, the rotation tends to persist. This is merely the inertia idea applied to turning motion. The **rotational inertia** of a body depends not only on how much it weighs, but also on how the matter is distributed around the center. That's why an engine flywheel has a thick rim; the greatest steadying effect results when most of the matter is far from the center.

Persistence of rotation is shown by the toy called a yoyo. It consists of two rather massive wooden discs mounted close together on a shaft to which a yard-long cord is fastened. Wind the string on the shaft between the discs, loop the free end around your finger and release the toy. The unwinding



Courtesy Sperry Gyros

The huge stabilizing gyroscope on the "Conte di Savoia"

of the string causes the double disc to spin faster and faster as it falls. When it reaches the bottom, the persistence of this rotation makes it wind up the string, rising again almost to the height of your hand. All that is needed to make it actually attain this height is a slight upward tug applied to the cord just before the discs are at their lowest point. A two-string version of the same toy can be made by thrusting a round pencil through a large apple and tacking two strings to the pencil, one each side of the apple. Incidentally, the arrangement descends with constant acceleration—like that of a freely falling stone, but in “slow motion.”

A pirouetting figure skater can make about thirty turns after one wind-up. After getting a start, he builds up his speed of turning by drawing hands and arms closer to the body, for it is a general fact that decreasing the rotational inertia of an object (by bringing some of it closer to the axis) automatically speeds up the spin. Try this stunt on skates, or by spinning on one heel on a smooth floor. Start with the arms extended sideward and, after setting yourself into rotation, draw your arms close to the body. The effect may be increased by holding a rather heavy weight in each hand.

Bend a hook on one end of a two foot length of wire, and hang a disc of heavy cardboard from this hook by means of a small hole near the disc's edge. Rub the upper end of the wire back and forth between the palms to produce a twirling motion. While in rotation the disc, which at rest hangs straight down, rises to a horizontal position. Every rotating object tends to set itself so that its rotational inertia with respect to the axis of turn is as large as possible.

There's a world of deep scientific knowledge to be gained by observing a simple toy like a spinning top. Every small boy knows from experience that a rapidly spinning top can

stand erect and even resist sidewise blows. What is it that makes a top stable while rotating, although it is unstable when at rest? A complete answer requires a complicated mathematical demonstration, which you certainly will not mind skipping over at present; but in a word, the reason is again: inertia. Not only does a spinning body tend to keep on turning, but it resists strongly any attempt to change the *direction* of its axis of spin.

Thus is explained the remarkable behavior of a **gyroscope**, which is merely a heavy-rimmed wheel mounted so that its axis can turn freely in several directions. Large gyros are used in practice to stabilize ships, to indicate the true north, and to pilot airplanes automatically. You'll get no end of satisfaction out of observing one of the very inexpensive gyros obtainable in a toy shop, making it do tricks like standing on a trapeze or walking a tightrope, revealing the less familiar facts of rotational inertia.

The whirling earth itself is a gyroscope. Its behavior is like that of a spinning top just before or after "going to sleep"—the axis leisurely swings in a circle. It takes nearly 26,000 years for the earth's axis to complete its round, and that means that the Pole Star—which happens to lie in the present direction of the axis—will some day be far from the true north, only to resume its present role after almost 260 centuries shall have passed.

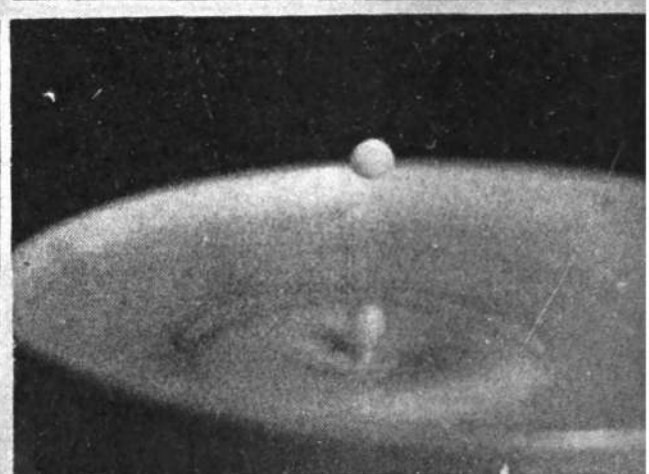
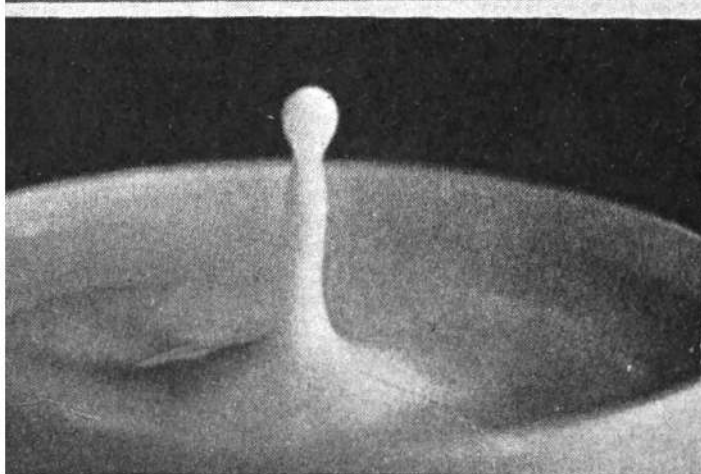
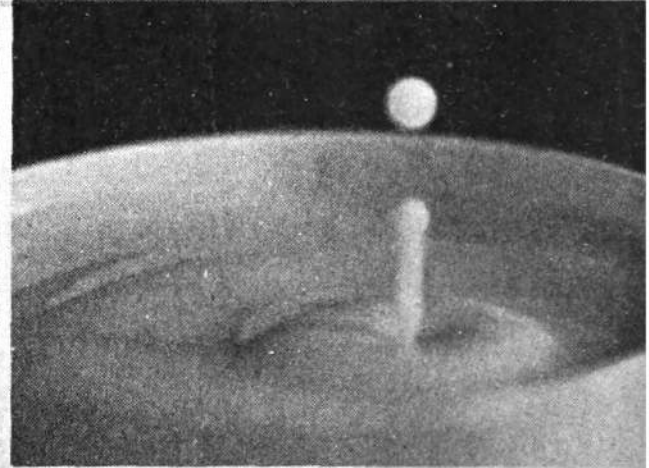
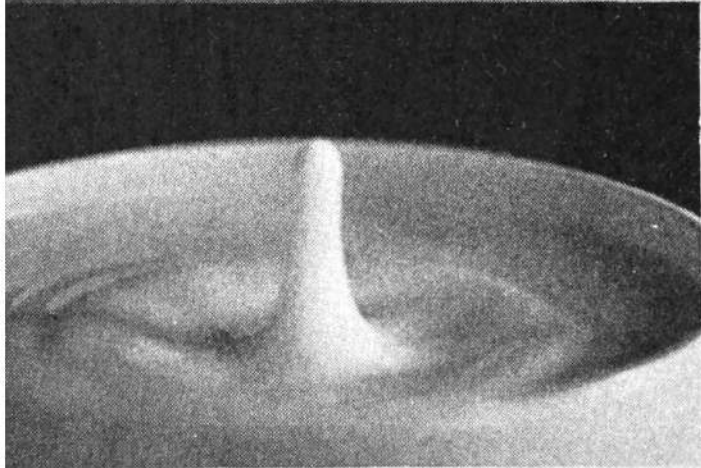
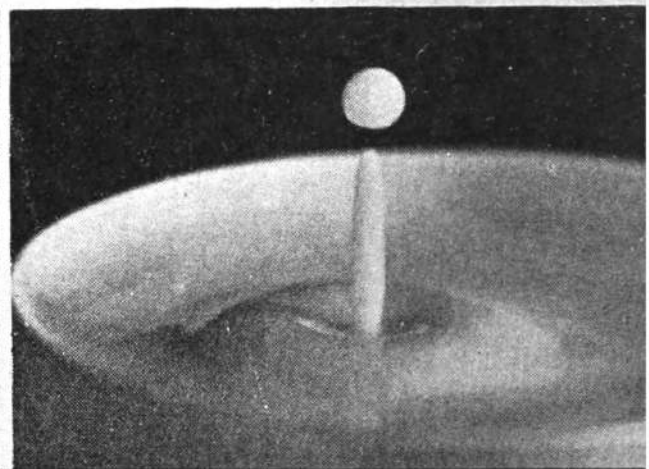
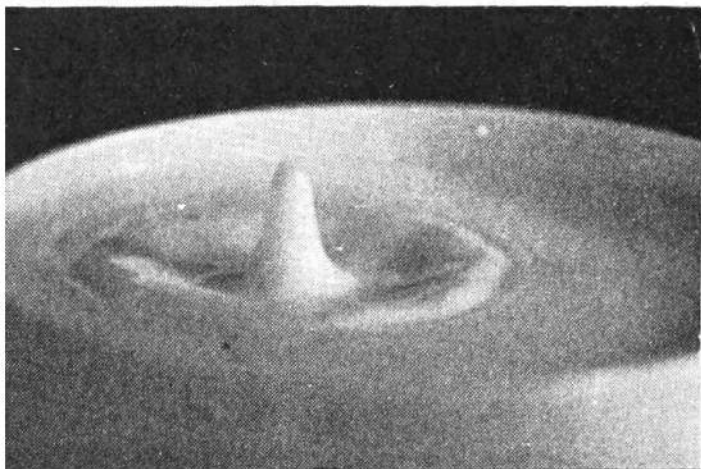
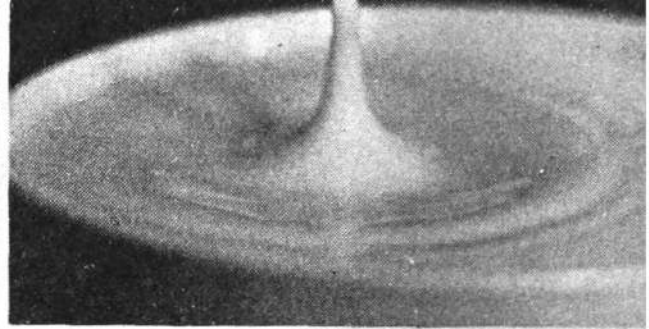
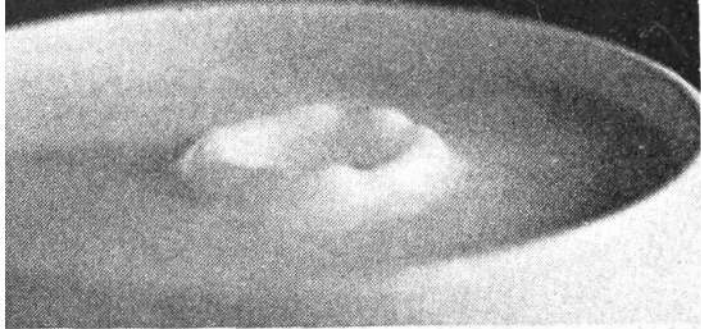
9

OF DROPS AND BUBBLES

THE forces compelling the molecules of a liquid to hug each other tightly are responsible for so many interesting phenomena that they deserve separate consideration. This clinging together of the molecules makes a liquid act as if its surface were a tightly-stretched membrane. A little water spilled into a clean dish spreads over the bottom, but in a greasy dish it collects in separate drops. In the first case, the attraction of the dish exceeds the attraction of the water molecules for each other, while in the second instance the water molecules are pulled more strongly by each other than by those of the surface on which they rest.

A falling drop, being free of the deforming effect of nearby things, tends to assume a spherical shape. Fill a toy balloon with water and close the neck tightly with a rubber band. Compare its shape, when suspended, with that of a drop of water about to fall from a dripping faucet. Lay the water-filled balloon upon a table and it takes the form of a flattened ball, like the drops on the greasy plate. But hang it in a pail of water and it rounds out to a sphere; the buoyancy of the surrounding liquid counteracts the deforming effect of the weight of the contained water, allowing the attraction of the molecules and the elasticity of the rubber to give the water within a nearly spherical form. This, of course, is the shape that has the smallest surface for a given contained volume.

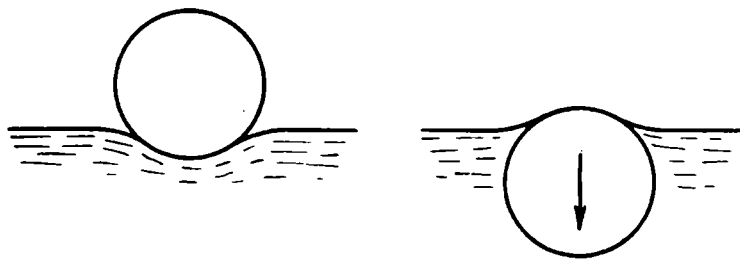
The tendency of a liquid surface to act like a stretched membrane is called **surface tension**. It is surface tension that



The play of surface tension: successive stages in the splash of a drop of milk
Photographed at $\frac{1}{1000}$ second, $f/2.8$, two No. 2 photoflood lamps

causes a thin stream from a faucet to pinch off into separate drops, or that makes it possible to pour water from one vessel to another along a previously moistened string. Cook books never call for "a heaping cupful of milk," but you can easily realize one, thanks to surface tension.

One of the most convincing ways to show the membrane-like nature of a water surface is to float carefully a razor blade, or a needle or paper clip made slightly oily by rubbing it through the hair. Look closely, and you will see that the liquid surface curves outward on all sides. The metal



Cross-section of a needle above and beneath the surface of water

floats *on* the liquid—not *in* it. Water fleas skim over the surface of a pond by virtue of the same effect. Once any surface-borne heavy object is pushed down into the liquid, it immediately goes to the bottom.

A tea strainer or a fine-meshed sieve whose wires have been made oily can be floated on water. Even more striking is the possibility of pouring water very carefully into such a sieve without any leaking through. A sudden jolt will then make the water run out in the expected way.

A floating razor blade is very fussy about the company it keeps. It tends to keep strictly to itself at the middle of a glass in which it is placed and, even when pushed toward the edge, returns to the center. It definitely avoids the proximity of floating bits of wood or cork, pushing them firmly

away, but another floating razor blade can be made to approach and touch it. On the other hand, two pieces of floating wood or cork will not only seek each other, but will eagerly go to the edge of the glass. The explanation of this lies in the fact that wood, cork, and glass are wet by water, while oily metal is not.

It may seem surprising that metals can be made to float, but equally irregular is the behavior of wood that does not float. Here again, surface tension is to blame. A checker or other small wooden object having a flat base is placed on the flat bottom of a dry tumbler, and is held there by means of a pencil while water is poured in. Slow and careful removal of the pencil leaves the checker at the bottom, and it remembers its ability to float only after the table is jarred, or a loud noise is made. Floating becomes possible only after the surface film between the sides of the wood and the glass is thus broken, permitting water to flow in beneath the wood.

Dissolving soap or other substances in water weakens the surface forces. Sprinkle talcum powder lightly over the entire surface of water in a clean soup plate. In this and the following experiments, all traces of grease must be avoided or the effects will not be observed. Touch a corner of a wet bar of soap to the water surface at a point near the edge of the plate. Instantly, the talcum is drawn over to the opposite edge, leaving a clear area of surface around the soap. Try the same procedure, substituting a drop of alcohol for the soap. This time the powder gradually returns to cover the entire surface as the alcohol evaporates. The explanation is that dissolving of soap or alcohol weakens the surface tension locally; normal tension over the rest of the surface pulls back the surface layer of water, and with it the powder used to make it visible.

Tie the ends of a four inch length of silk thread together

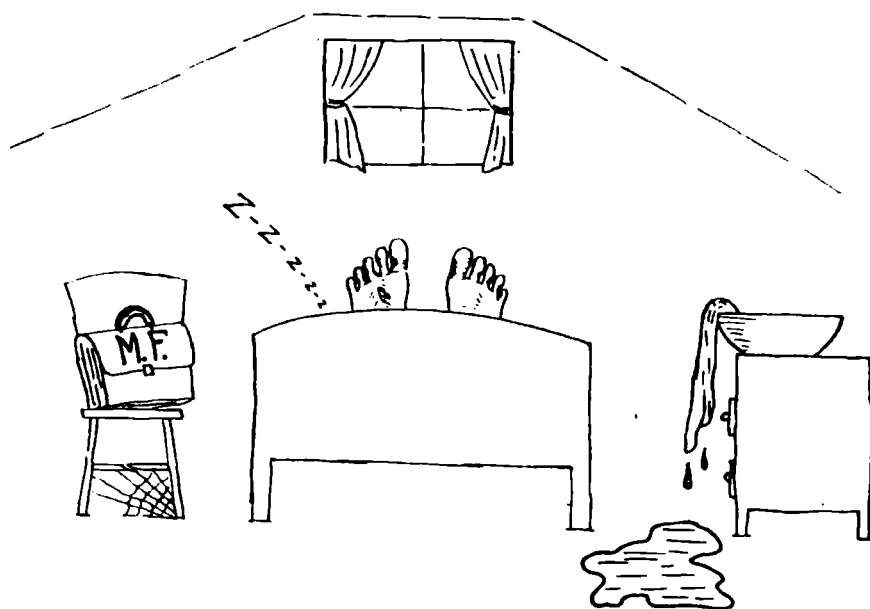
to form a loop, which is floated on water in a clean dish. Touching a piece of wet soap to the surface inside the loop makes it snap out into a perfect circle. Why a circle? Because the normal surface tension of the water outside the loop tends to pull the thread as far out as possible all around, and the circle is the shape that encloses the largest area for a given distance around.

Dig a tiny speck of soap from a bar, using a pin, and drop it on a clean water surface. It will dart around erratically like a thing alive as it dissolves first at one point and then another. Soap is admittedly a powerful agent in modern civilization, but did you know that it is capable of propelling a boat? Rub one end of a match stick on wet cake of soap and float the stick in clean water. The soaped end becomes the stern of the active but undecided boat. Even the slight contamination produced by touching a finger to the scalp and then to the water is enough to slow the activity of the boat, eventually stopping it.

If one end of a very narrow glass tube is dipped in water, the liquid will rise inside the tube until it is some distance above the level outside, in apparent contradiction to the familiar principle that the level should be everywhere the same. But in fine-bore tubes, the surface forces get the upper hand; they have everything to say about what happens. Because of the attraction of glass for water, the upper surface of the water inside the tube assumes a dished-in shape. Its tendency to straighten out pulls the liquid up, the water literally hanging from the surface film. This elevation of liquids in narrow tubes is called **capillary action**. You can observe it if you have at hand a fine tube, such as a broken thermometer stem; or heat a piece of glass tubing—say a medicine dropper—by rotating it between the fingers while keeping the center

in a narrow gas flame, draw it out while hot, and carefully break off a length of the center section. Color the water with a little ink or bluing to better observe its rise within the tube. The height of rise is greater when still finer tubes are used. Water will rise nearly 4 inches in a tube $1/32$ inch across.

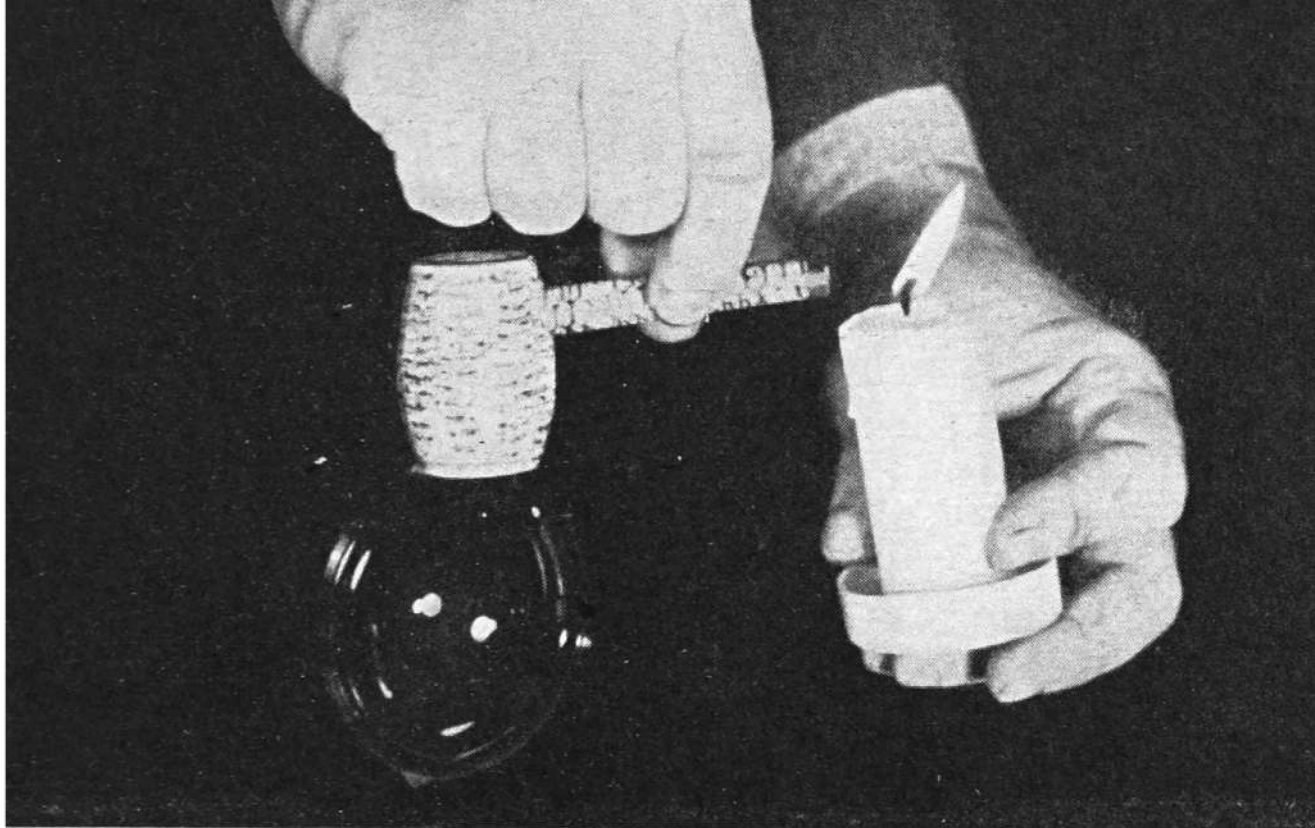
It is related that MICHAEL FARADAY, one of the greatest scientific experimenters of a century ago, went to sleep one night, carelessly leaving a towel hanging over the edge of a half-filled wash basin. In the morning, the usually meticulous



Faraday's oversight

scientist found to his consternation that the bowl was empty, the floor wet. Capillary action made the water rise in the pores of the cloth, after which it descended to the floor by its own weight. Capillarity is responsible for such effects as the absorption of ink by a blotter, or the soaking-up of water by a sponge.

One of the most beautiful manifestations of surface tension is a fragile, iridescent soap bubble. A solution that makes



Air from the contracting bubble blows the flame aside

good, lasting bubbles may be prepared by dissolving an inch cube of pure Castile soap in a pint of water, preferably distilled water, and adding a little glycerine. In the absence of a pipe, an ordinary soda straw will serve for blowing the bubbles.

After blowing a bubble a few inches in diameter, keep it on the pipe and remove the other end of the pipe from your mouth. The tendency of the bubble to contract like a rubber balloon forces the air out—slowly at first, and more briskly as the bubble shrinks. Test this by holding a lighted match or candle near the end of a rather wide-stemmed pipe. Remove the mouthpiece if possible. The flame blows aside as the bubble becomes small.

A spectacular experiment, but one requiring a bit of caution, involves the inflation of a bubble with illuminating gas, using a rubber tube attached to a gas jet. Detaching the bubble, let it come to rest on the ceiling, and ignite its contents

by means of a lighted candle on the end of a stick. Keep away from curtains or other inflammable material.

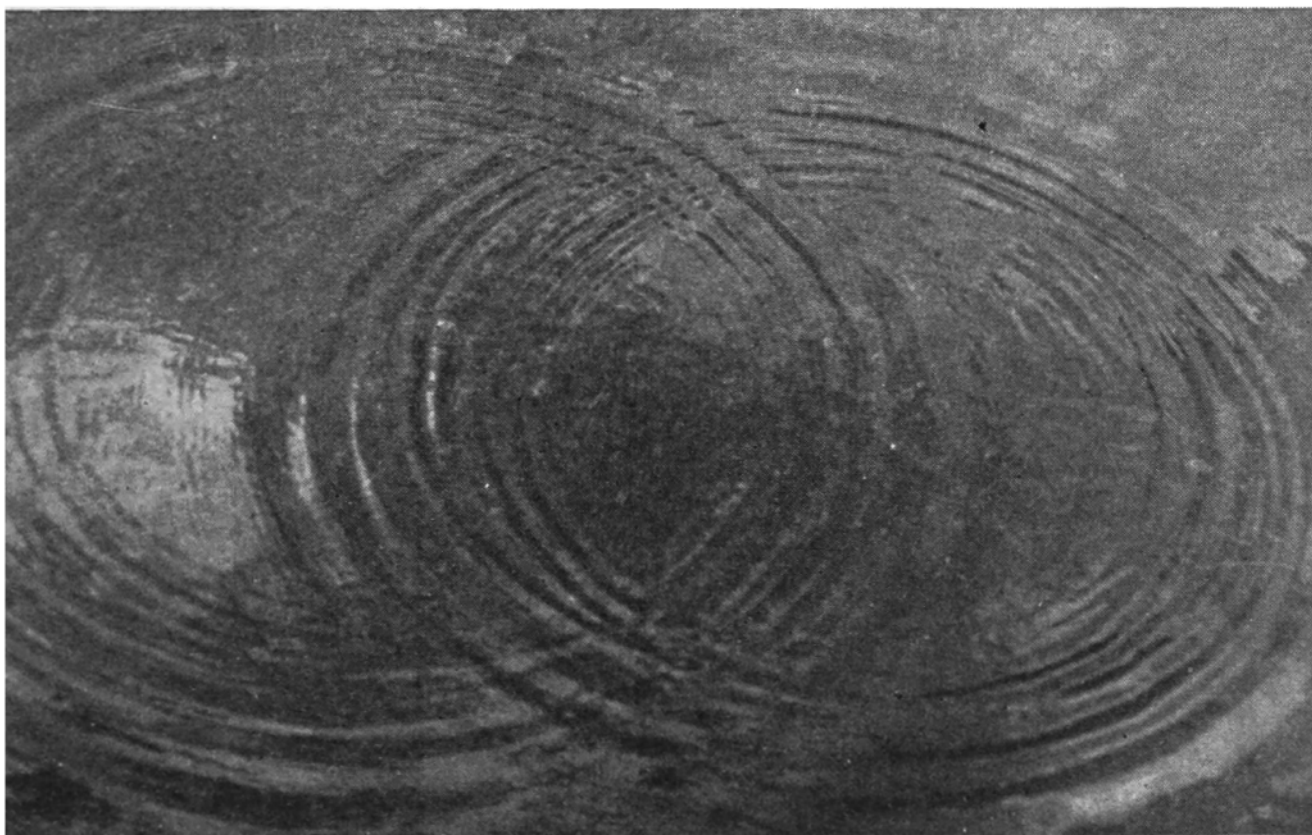
Blowing bubbles is no idle occupation, for recent research shows that the study of surface layers of liquids may lead to important discoveries in the world of living matter, where surface forces seem to play an especially significant part.

10

SOUND COMMENT

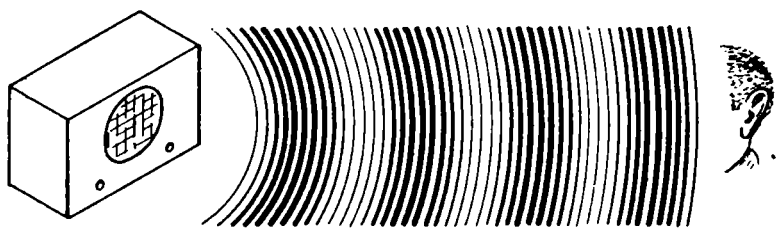
A stone dropped into a quiet pond gives rise to a set of circular ripples or waves spreading outward over the surface. A piece of cork or a floating chip of wood encountered by the advancing waves does not move forward with them, but merely bobs up and down in one place. LEONARDO DA VINCI, that versatile Italian genius of art, science and invention, watched waves move across a wind-swept field of wheat, and recognized that the forward motion of the grain was an illusion; each stalk simply vibrated back and forth as the wave passed. In any wave, it is only the *form* of the disturbance that moves along, while the individual parts of the material

Two sets of waves interpenetrate without destruction



carrying the wave merely **vibrate** back and forth as the wave passes.

Besides waves on water, on grain, on a flag fluttering in the breeze, there are other types. If a charge of powder explodes, the air immediately surrounding it is suddenly compressed. Its elasticity makes it expand again, and in doing so it compresses the air just beyond. The compression is handed on, and spreads rapidly outward from the center of the disturbance in the form of a wave of compression, or **sound**



Sound waves

wave, for that is what sound is: a wave that crowds together, then draws apart the molecules of the air as it passes. The sensation of sound is obtained when a wave of this kind hits the ear.

Compressional waves (sound waves) can travel through such materials as water and steel, as well as through air. Under usual conditions the speed of sound in air is about 1100 feet per second—about 750 miles per hour! In water, it goes 4 times as fast, in steel $14\frac{1}{2}$ times. Notice the delay between the instant you see a puff of steam from a distant whistle and the arrival of the sound. Or determine how far away a thunderstorm is by counting the number of seconds between the lightning flash and the report of the accompanying thunder. Since you see the flash almost instantly, while the sound takes about five seconds to go a mile, merely divide

the number of seconds by five and you have the distance in miles.

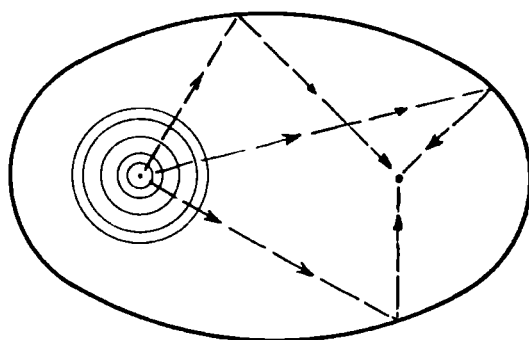
An **echo** results when sound waves are thrown back from a surface far enough away so that the returned sound is distinguishable from the original. You can make a mechanical “model” of an *écho* by tying one end of a heavy cord or rope to a chair or doorknob, taking the other end in your hand and giving it a sudden downward jerk. A “wave” travels along the suspended rope and is “reflected” from the fixed end, returning to your hand. Several reflections may be observed before the wave dies out. Ocean depths are now measured by sending a sound wave down to the bottom and measuring the time it takes to return to the surface.

Another way to study waves is by using a ripple tank. Merely take a large, shallow pan—preferably one with straight sides—put some water in it, and start a wave moving toward one end with a brisk sideward sweep of a table knife or a slat. Observe the reflection of the waves from the ends. The motion is more easily followed if you place an unshaded light high above the pan and watch the movement of the wave shadows on the bottom.

Sound waves, and other waves as well, can be concentrated by reflecting them from a curved surface. In Statuary Hall of the Capitol at Washington, a person standing a few feet from the wall can hear the whispering of another person who stands facing the wall at the corresponding point on the opposite side, 50 feet away. At in-between points, the sound is not heard. The auditorium of the Mormon Tabernacle at Salt Lake City and the dome of Saint Paul’s Cathedral in London are other famous “whispering galleries.” Observe the same effect with ripples in an oval bowl or basin. Start a wave by letting fall a pebble or a drop of water at one **focal point** (see

figure) and notice the way in which the reflected wave closes in to the opposite focus.

And now make a real whispering gallery by using two open umbrellas as sound reflectors. Prop them up several yards apart, with the handles horizontal and facing each



Focusing of sound in a "whispering gallery"

other and in the same straight line. Fasten a watch to the stick of one umbrella at a point a little less than half way from the crown to the handle. Placing your ear at the corresponding point of the other umbrella, you will hear plainly the ticking of the watch.

The disturbance produced by dropping a stone into water consists of only a few crests and hollows. If you want to produce a continuous set of waves, you must have an oscillating, or vibrating, body as the source of the disturbance. For example, such waves are obtained in the ripple tank by dipping the knife blade in at regular intervals. Exactly the same thing is true of sound waves: Sustained sounds come from such things as vibrating bells, violin strings, drum-heads.

To realize that sources of tone are actually vibrating, just consider that simplest of all musical instruments, the tissue paper and comb. The tingling sensation felt by your lips is due to the rapid vibration of the paper.

Tie a bead or small button to one end of a piece of thread. Place a stemmed wine glass upside down on the table. With adhesive tape, fasten the other end of the thread to the edge of the base, so that the bead hangs in contact with the bowl of the glass not far from its lip. If, now, the glass is lifted by the base and caused to emit a tone by striking it, the vibration is made evident by the fluttering motion of the bead and by its tinkling against the glass. These effects continue as long as the tone is heard.

Put some water in a wine glass or thin tumbler. Holding the base firmly to the table, rub a moistened finger along the edge of the glass and it emits a squeaky tone. At the same time, observe the water surface closely by looking at it against a light and notice that it is covered with a stormy ripple pattern.

If the vibrations of a sound source—and therefore of the air waves coming from it—are perfectly regular, you perceive a definitely pitched **musical tone**; if the vibrations are unevenly spaced, or if there is a jumble of unrelated vibrations, you hear a **noise**.

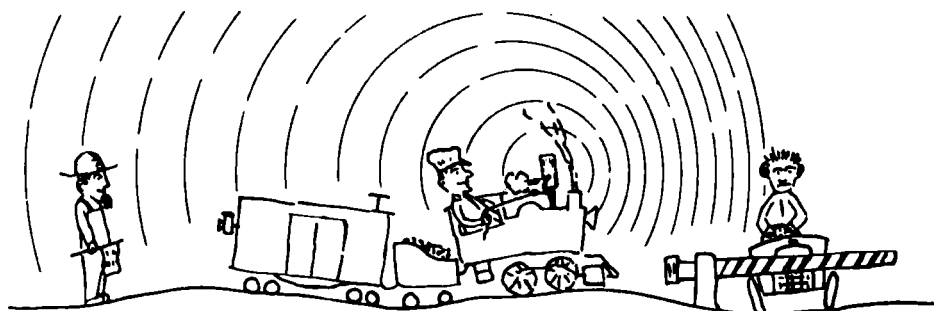
Draw the tip of your finger nail across a ridged linen book cover and observe that the pitch of the sound produced depends on how fast the finger is moved. The more rapid the motion, the higher the pitch. What we mean by the pitch of a sound is merely the rate at which waves strike the ear, which is the same as the number of to-and-fro wiggles that the source of sound makes each second.

In the case just mentioned, your nail is caused to vibrate back and forth at a regular rate as it slips over the evenly-spaced ridges. For a similar reason, a strip of paper held lightly against the blades of an electric fan gives off a tone whose pitch becomes higher if the fan speeds up. A tone of

definite pitch will be noticed following a single clap of your hands while standing in front of a long flight of steps, or alongside a picket fence. That's because the single sharp noise is reflected back to your ear at regular intervals from the successive evenly-spaced steps or slats.

The human ear is capable of detecting sounds only if the number of vibrations each second is between about 20 and 20,000; if the rate of vibration is outside these limits, the ear does not respond. Most of the frequencies used in speech and music lie between 30 and 5,000.

Sounds differ in loudness. Since the waves spread out like ripples on water, the sound becomes rapidly weaker as it travels away from the source. At twice any given distance from the source it is only $1/4$ as loud, at three times the distance $1/9$ as loud, and so on. The loudness of a sound is described by telling how many times it exceeds the faintest sound detectable by a normal ear. On this basis, the rustling of leaves in a light breeze has a loudness of 10 **decibels**, whis-



The pitch of the whistle seems higher to the man ahead of the train and lower to the man behind

pering about 25, loud music 75, and thunder 100 or more.

Suppose you are standing beside a railroad track as a locomotive approaches with its whistle blowing. Apart from changes in loudness, you notice an abrupt drop in the pitch

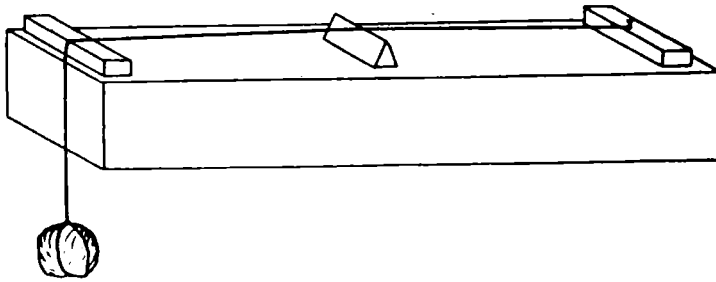
of the sound as the train sweeps by. The same effect is perceived if, while riding in a train, you pass a warning bell at a crossing. In both cases, the pitch is *higher* than normal while *approaching*, *lower* while *receding*. In order to understand how it is possible for motion of the source or hearer to affect the apparent pitch of a constant tone, remember that the ear judges the pitch of a sound by the number of waves that strike it each second. When the listener and the source of sound are approaching each other, the waves strike the ear more frequently than when both are at rest, and a higher tone is perceived; when the two recede from each other, fewer waves hit per second, producing the impression of a lower tone. A similar effect is noted with light waves.

11

MUSIC IN THE AIR

MUSICAL instruments like the violin, guitar and piano produce their tones by means of the vibration of stretched strings or wires, and are called **stringed instruments**. The strings are set into vibration by bowing or plucking, or by striking them with padded hammers. Since this is one of the more important classes of musical instruments, some experiments on vibrating strings are in order.

Construct what amounts to a one-string guitar by stretching a wire or gut string tightly over two wood blocks resting on the surface of a long, thin-walled box. Use a strand of rubber if a real string is not available. A triangular piece of wood slightly taller than the blocks is used as a movable bridge.



The basic stringed instrument

With the bridge removed, pluck the string and listen to the tone it emits. Then, place the bridge under it at its exact middle, and pluck either half. You will at once recognize the new tone to be an octave higher than the first. Two notes an octave apart constitute the simplest possible combination

of tones. Moreover, it is an interesting fact that the theory of vibrating strings shows that the half string must vibrate at exactly twice the frequency of the whole string. For example, if the whole string makes 100 vibrations each second, the same string bridged at the middle would make exactly 200.

Now Western music—and by that we mean Occidental music, not the cowboy variety—is based on a scale made up of six additional tones that divide the two-to-one interval of the octave into simple fractional parts. These notes form the familiar **do, re, mi . . .** sequence. Sound the **fundamental** (full string) tone and then, by ear, set the bridge successively at the positions that give the remaining notes of the octave. Mark each position on the top of the box. If the tuning is carefully done, the distances of the marks from the fixed end of the string will measure

$$\frac{8}{9}, \quad \frac{4}{5}, \quad \frac{3}{4}, \quad \frac{2}{3}, \quad \frac{3}{5}, \quad \frac{8}{15}, \quad \frac{1}{2}$$

of the total string length. Calculation shows that the vibration rates of the tones in the scale are related by these fractions turned upside down, or as

$$1, \quad \frac{9}{8}, \quad \frac{5}{4}, \quad \frac{4}{3}, \quad \frac{3}{2}, \quad \frac{5}{3}, \quad \frac{15}{8}, \quad 2.$$

do re mi fa sol la ti do

You are at liberty to begin the octave with a tone of *any* frequency; these ratios then tell how to build up the entire scale.

In order to permit what musicians call the **transposition** of a melody, it turns out that slight adjustments in pitch are required and that five additional tones must be inserted in the octave. These correspond to the black keys on the piano.

Two or more tones that sound well together are said to be **consonant**; combinations that clash unpleasantly are called

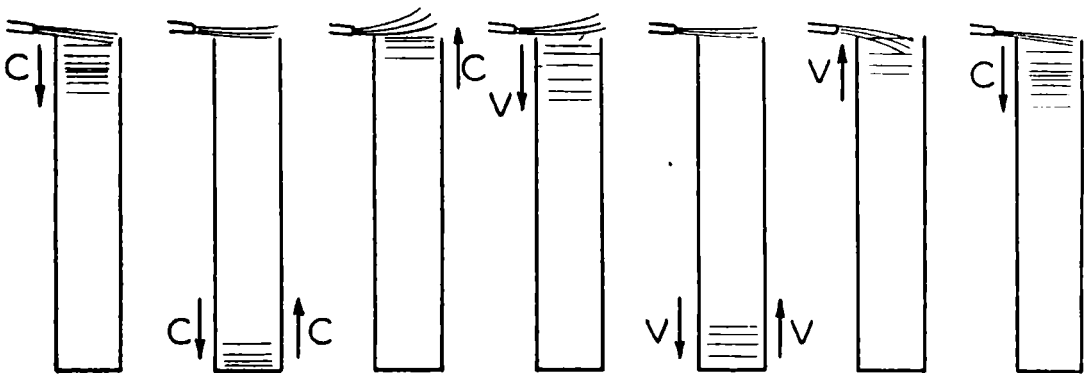
dissonant. Place the bridge under the string and pluck both sides at the same time. Do this for several positions, and note the lengths of the sections of the string in each case. For the pleasant-sounding combinations, the lengths will be in the ratio of small numbers such as 2:1, 3:1, 3:2, 5:4, etc.; dissonant combinations will be 9:8, 15:8, and other more complicated ratios. There seems to be something about the ear that makes it prefer simple arithmetic!

Place the bridge of the one-string guitar at a point $\frac{1}{3}$ the distance from one end of the string. Place a little V-shaped paper rider on the string at $\frac{1}{4}$ the length of the longer segment, another at $\frac{1}{2}$, and a third at $\frac{3}{4}$. Carefully pluck the short segment of the string at its mid-point, and observe that the first and third riders are thrown off, while the middle one remains on the string. This shows that the string, because of the way it was supported and plucked, divided itself into three **loops**. The first and third riders flew off, since they were intentionally placed at loops, where the motion is greatest; the middle one remained because it was placed at a stationary point, or **node**. A string can be made to vibrate in two, three or any whole number of loops, giving out tones whose frequencies are in the ratio 2:3:4 . . . to the fundamental (single loop) tone. These are called the **overtones** of the string. Demonstrate the "overtones" of a heavy rope by tying one end to a fixed support, holding the other end in your hand, and shaking it up and down. First move your hand at such a rate that the whole string forms one loop; then, by shaking it at exactly twice this rate, you can make the string divide into two loops, with a node between, one loop going down while the other goes up. Three times the frequency makes the cord break up into three loops, and so on.

Not alone strings, but other sources of sound as well, emit overtones; and usually the vibration consists of a mixture of the fundamental and several overtones. In fact, it is the number and relative strength of the overtones that enables you to distinguish a note sounded on the flute from a tone of the same pitch played on the violin or trombone. This difference is, as the musicians say, one of **tone quality**.

Another important class of musical instruments makes use of compressional waves traveling in pipes or tubes. The flute, cornet, clarinet, pipe-organ belong to this group, and are called **wind instruments**. Simplest of all such instruments is a tube, closed at one end and blown at the other by directing a stream of air from the lips just inside one edge of the tube. Try it with several pipes of different length and perceive that the longer the tube, the lower the tone it emits. Use bottles of various sizes if no tubes are at hand—the essential principle is the same.

Here's what happens when you blow across the mouth of a tube: The air jet, blowing into the pipe, builds up a bit of extra pressure there, and this region of compression streaks down the tube with the speed of sound. When it hits the closed end it bounces back, traveling again to the open end. Here it encounters no fixed wall; on the contrary, it escapes



Sound waves in an organ pipe

into the open air so suddenly that the pressure is momentarily lowered and a partial *vacuum* now goes back to the lower end. When this vacuum returns to the top it pulls the air jet into the pipe once more, causing the pressure to build up, and the whole process repeats again and again in the interval that it takes sound to go four times the length of the tube. The surrounding air is set into vibration in this regular tempo, and so a continuous note is given off. The longer the pipe, the longer the interval between pulses, and the lower the tone.

. While some organ pipes are closed at one end like the tube just described, most of them, as well as almost all other wind instruments, are open at the far end. The principle is the same as before, except that now the pulse has to travel only once down and once back along the tube to complete a cycle of events. Result is that such an open pipe has twice the frequency (the octave) of a closed pipe of the same length. This is best shown by blowing a given tube—first open, then closing the far end with the finger. The octave jump in pitch will be apparent. An interesting fact is that a pipe carrying sound waves behaves exactly like the rope on page 96. The pipe can be made to give off overtones as well as its fundamental tone, and the air in it can be made to break up into “segments” just like the rope. But in this case the overtones are brought out by more vigorous blowing. Try this with a tube or bottle, or with a flageolet (tin whistle). The overtones, already present, are made more prominent, one after another, by stronger and stronger blowing.

In some organ pipes, and especially in instruments like the clarinet and saxophone, the air blast is supplanted by a flexible, vibrating reed. In the brass instruments, the tightly-stretched lips of the player take the place of the reed. All of these instruments are “open pipes” of course. The player

changes the effective length of the pipe—and therefore the tone given out—in the case of flute, clarinet and the like by uncovering holes along the pipe. When the sound pulse gets to an opening, it is free to communicate with the outside air; the remainder of the tube has no effect. Instruments like the cornet and the tuba are made to produce their various notes by shunting in additional lengths of tubing by means of valves. In the slide trombone, continuous (“sliding”) changes of pitch are possible.

Drums, bells, the xylophone and marimba—all are called **percussion instruments**. The tone is produced by striking bars or plates or membranes, causing them to vibrate and to communicate their motion to the surrounding air.

Have you ever noticed that small people are generally more active and move faster than large individuals? We already saw that a similar thing is true of sources of sound: Short strings and short pipes vibrate at a greater rate than long ones. And so it is with percussion instruments, too. Small plates and bars give off tones of higher pitch than do large ones. The noise made by a dish or bottle that falls and shatters, while it lasts only a fraction of a second, is perceptibly higher in pitch toward the end of the crash. That is because the first noise is that produced by vibration of the still whole object, but as it breaks up into smaller and smaller pieces, these give off tones of higher and higher pitch. Radio sound-effects men simulate the noise of breaking glass by dropping a number of various-sized metal plates onto a hard surface.

Knowing this much, you can now recall that the shortest bars of a xylophone produce the highest notes. It is instructive to build a simple instrument of this kind. Procure a number of hardwood sticks, all of the same cross section, or use metal bars cut from a rod or metal strip. In order to obtain

the whole notes of the octave, the bars must be cut to lengths that are in the same relation as those of strings emitting tones of the scale. As on page 95, these lengths must be

$$1, \quad \frac{8}{9}, \quad \frac{4}{5}, \quad \frac{3}{4}, \quad \frac{2}{3}, \quad \frac{3}{5}, \quad \frac{8}{15}, \quad \frac{1}{2}.$$

Once they are cut, fasten the bars in order, one below the next, to two suspended cords. Tie the strings to each bar at a point about a fifth of the way inward from each end. A stick or small mallet may be used to strike the bars.

A bell is merely a curved metal plate and, as you might expect, the complicated shape causes the plate to emit a complex set of tones. Besides the fundamental, several overtones are usually recognizable, especially in the case of large bells. But the overtones of bells, unlike those of strings or pipes, are not harmonious among themselves—very often there is an unpleasant discordant effect, especially noticeable near a large bell.

Convert an ordinary silver tablespoon into a church bell by tying two yard-long pieces of string to the handle at a point near the bowl. Pack the free end of each cord into one ear, holding it there with a finger, and strike the suspended spoon against a hard surface. The resemblance to the tones of a bell, both in quality and loudness, is startling. The sound is loud because the cords communicate the spoon's vibrations to your ears with little loss.

Tunes can be played on a set of thin tumblers or wine glasses, each filled by trial to the proper depth with water and set into vibration by striking with a stick or by rubbing the edge with a moistened finger.

Now, in contrast with the last experiment, pour water into

a *tall* jar or vase. The pitch of the tone goes up as the water rises. In the previous experiment, the tone was due largely to the vibration of the glass itself; here, the jar acts like a closed organ pipe—the tone is that of the slender air column, and you already know that it should become higher pitched as the tube is effectively shortened by filling it with water.

This ability of a tube to respond to one particular frequency is an example of a highly important and useful phenomenon called **resonance**, and it's not confined to sound vibrations. Take the case of that childhood delight, the swing suspended from the limb of a tree. In order to get it swinging high, you don't push it at random, but in the exact tempo of its natural to-and-fro motion; and even a very slight push applied each time it reaches its highest point will soon build up a wide swinging motion. That's resonance. Consider a suspension bridge. It, too, has a natural period of vibration. Soldiers marching across are told to break step, so that the impacts will not build up a dangerously wide swing if their timing happens to be the same as the natural vibration of the structure.

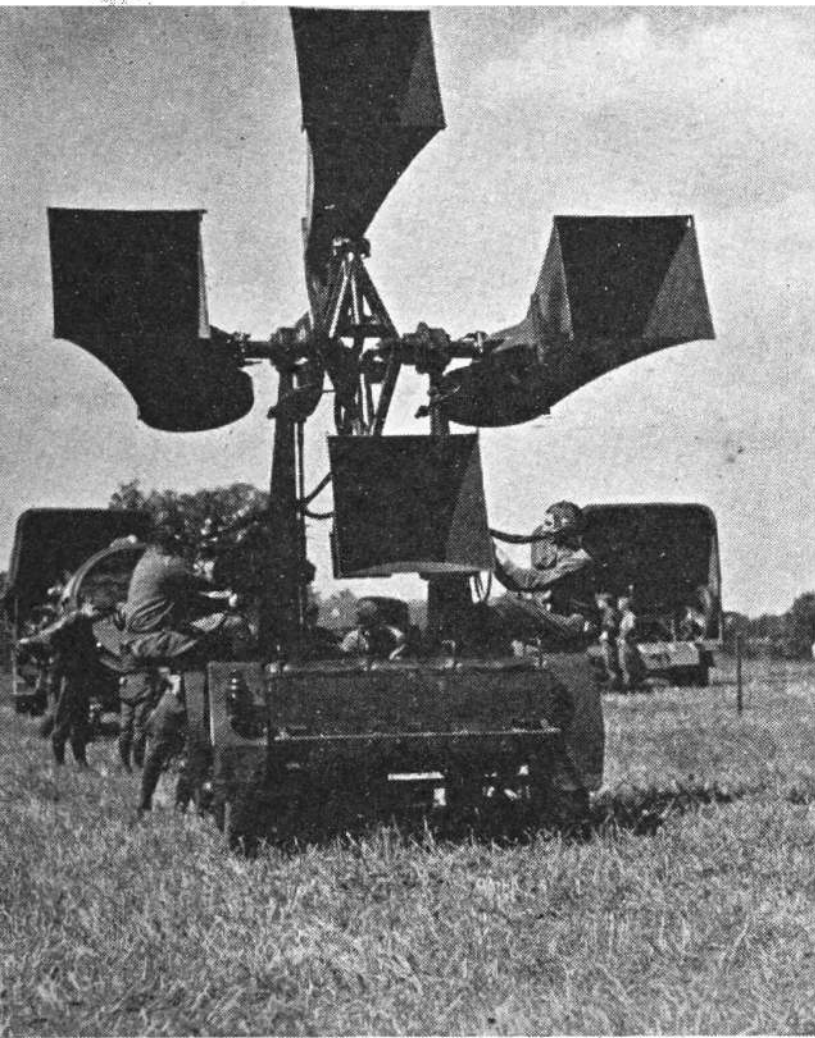
A really surprising case of resonance in sound is that of the "singing piano." Open the cover of a piano, push down the "loud" pedal to release the damping mechanism, and sing a single, short tone into the strings. You already know that your voice is rich in overtones. Each piano string that corresponds to the pitch of one of these overtones is set into vibration by it through resonance, and so after the original sound has stopped, the continuing vibrations give back a fairly good reproduction of the original tone. Your ear responds to sound in much the same way as the piano strings in this experiment. In the inner ear are thousands of tiny

filaments (strings) which respond by resonance to the various frequencies detected, transmitting them to nerves communicating with the brain.

Perhaps you're an addict of that favorite American pastime, singing in the bathtub. Don't be ashamed of the habit—it can be put to scientific use. When next you feel like indulging in this habit, place your head directly above a wash bowl and hum loudly, starting with a low note and gradually raising the pitch. At a certain pitch you will find the bowl strongly reinforcing your voice tone, responding to it by resonance. An entire room, especially a small one, can sometimes be made to resonate in this way. Men are more frequently bathroom vocalists than are women because the resonance is better for the lower tones of the male voice.

Resonance, while very useful, must be controlled in building musical instruments. If the body of a violin responds more to a certain tone than to others, the unduly loud result is a "wolf note," as musicians say. The old Italian masters evidently knew the secret of putting together thin plates of rare wood to form violin bodies that respond equally to all tones of the instrument. The sounding board of a piano must be capable of vibrating with the frequency of *any* string. Its purpose is to make the emitted tone louder by allowing the string to transfer its vibration to a large surface capable of setting a considerable amount of air into vibration. The sounding board is said to respond by **forced vibration**. The paper cone of a radio loud speaker and the diaphragm of a phonograph act in the same way. They must have no natural frequencies of their own in the range of tones to be reproduced, or the resulting sound will be "tinny".

A good experiment on forced vibrations that can be made right at the dinner table consists in pinching together the



*Four ears are
better than two
for locating
hostile aircraft*

Courtesy U. S. Army Signal Corps

prongs of a fork, so that they continue to vibrate. The sound persists for some time, but is very faint because the narrow tines cannot set much air into motion. Press the tip of the handle of the fork firmly down against a hard table-top. The tone at once becomes louder; however, it now dies away quite soon because the energy of the fork's vibration is dissipated more rapidly.

If you have never, as a child, made a string telephone, you'll find it an entertaining experiment in forced vibrations. A small hole is punched in the center of the bottom of each of two heavy paper drinking cups or baking powder cans and they are connected by a string several yards long. Words

spoken into one of the units are heard with surprising loudness and clarity by another person who places his ear close to the second 'phone. Keep the cord fairly taut for best results.

Why did Nature give us two ears? Is it in order to hear twice as much? There's a much better reason than that. Blindfold a person, stuff one of his ears with cotton, and ask him to locate a watch concealed somewhere nearby. His amusing blundering will bring home the fact that we judge the direction from which sound waves come only by comparing the loudness in our two ears. A military sound detector uses two huge sound-collecting horns set many feet apart and connected one to each ear of the listener. The entire instrument can be turned in any direction, and when the sound of an enemy plane appears to be equally loud in the two units, it is known to be directly ahead of the horns. Two additional horns are used in the same way to determine the elevation of the object.

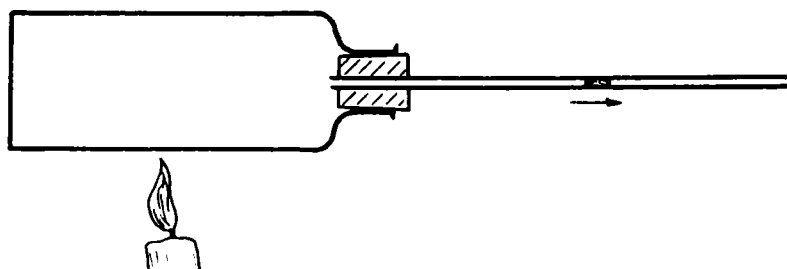
UP AND DOWN THE THERMOMETER

EVERYBODY is able to distinguish between a warm day and a cold one. A special set of nerve endings in the skin tells us the difference. But the message sent to the brain may depend on other factors than the actual temperature of the air; it may be influenced by winds, by sunshine, by the amount of moisture in the air, and so on. You yourself, mopping your forehead on a sultry summer day, have probably said "It isn't the heat—it's the humidity." And so our feelings are not sufficiently reliable for a precise, scientific measurement of temperature. A simple experiment to try in this connection is to place three vessels in a row—the first filled with cold water, the second with lukewarm water, the third with rather hot water. Place the left hand in the cold water, the right hand in the hot. After several seconds, remove and plunge them at once into the middle vessel. The lukewarm water in it will seem hot to your left hand and at the same time cold to your right, although you know it must be the same temperature throughout.

Experiments like the last one show that some other,—some more "impersonal" way must be found to measure temperature. Observation shows that a metal rod becomes longer, the volume occupied by a liquid or gas becomes larger, as heat is supplied. In common language, we say "Heat expands and cold contracts," but we must make certain we understand exactly what this means.

Insert a length of narrow glass tubing or a soda straw into

a snugly-fitting hole in the cork of a bottle and introduce a drop of water or oil into the tube. Grasping the bottle in the hand or bringing a lighted candle near it expands the contained air, moving the drop outward along the tube. This



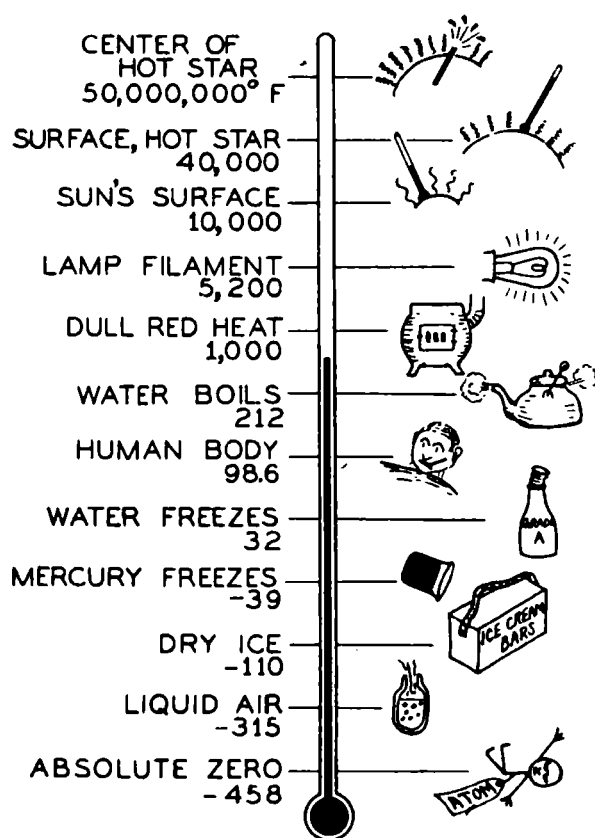
An air thermometer

crude instrument is similar to the first fever thermometer constructed by GALILEO toward the end of the sixteenth century.

Carefully warm a milk bottle by holding it by the mouth high over a gas flame, put some vaseline or grease on its lip and set this end down on a flat plate, twisting the bottle slightly as you press it down. After waiting a bit until the glass cools, you'll find it possible to lift the plate by picking up the bottle. Warming the bottle expands the air in it—drives part of it out, so that when the closed vessel cools, the pressure within is lower than before.

Fill the bottle of your air thermometer completely up to some point in the tube with colored water, or better, with alcohol or mineral oil. It is best to fill the bottle with cork and tube removed, then replace them, taking care to force out any remaining bubble of air by pushing the cork in. Now place the bottle in a vessel of hot water and notice that the liquid in the tube rises. Liquids, too, expand when warmed, but not as much as gases. Save the parts of the fluid thermometer for later use (page 117).

The common mercury thermometer makes use of the expansion and contraction of the liquid mercury to indicate temperature changes, the very slight change in bulk being made more evident by attaching to the bulb a very fine tube. But the household thermometer has something more than the instrument we constructed,—it has a **scale of degrees**, on which the exact value of the temperature can be read. The scale in general use in English-speaking countries was devised by GABRIEL FAHRENHEIT of Danzig about a hundred years after Galileo constructed his instrument. FAHRENHEIT wanted to avoid “below zero” numbers on his scale, so he had the thermometer exposed to what he considered the coldest weather generally experienced; the position on the tube where the mercury came to rest he called zero degrees (0°).



Temperatures here and there

Then, as the second reference point, FAHRENHEIT chose the temperature of the human body; he seems to have called it 96° . Knowing that mercury expands uniformly, he divided the distance between these two marks into 96 equal parts, each one being 1° . It just happens, as you know, that the mercury stands at the 32° mark when the thermometer is put into ice water and at the 212° mark when it is held in steam rising from boiling water. The first is called the **freezing point**, the second, the **boiling point**. Average human body temperature is now taken to be 98.6° Fahrenheit.

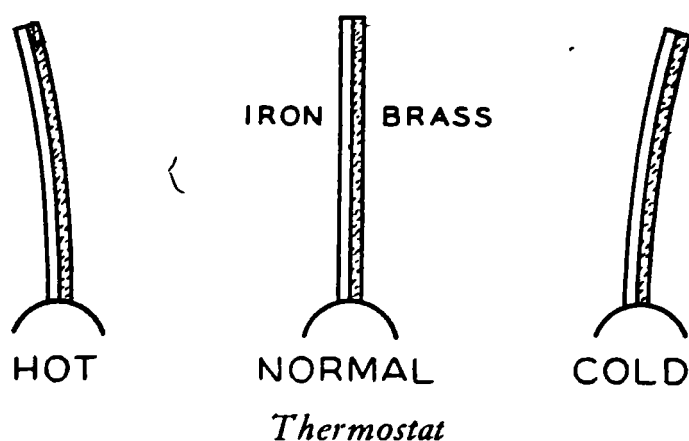
In scientific thermometry another scale, called the **Centigrade** scale, is used. It has the freezing point marked 0° , the boiling point marked 100° .

Perhaps you have had the unfortunate experience of pouring hot tea or boiling water into a thick tumbler, only to have it crack. A thin glass, on the other hand, is usually able to withstand the sudden heat. The reason is that glass, like most substances, expands when heated. The inner part of the thick glass expands before the heat has time to penetrate to the outer part, and the resulting strain cracks the tumbler; but the thin glass quickly heats all the way through and cracking is prevented.

Different substances expand at different rates when warmed. An iron bar a foot long increases in length about $1/70$ inch when heated from the freezing point to the boiling point. A brass bar expands about $1\frac{1}{2}$ times as much under the same conditions, while a glass rod expands only $\frac{1}{2}$ as much as an iron one. Special kinds of glass, used in making baking dishes, have much lower rates of expansion.

If a strip of iron and a strip of brass are welded together along their length, the difference in their expansion rates shows up easily by the fact that the double strip bends into a

curve when heated, the brass being on the outside. Upon cooling, the pair again straightens out. A strip of this kind is used in **thermostats** for automatically regulating the temperature of furnaces, and in fire alarms, where the curling of the strip closes an electrical contact that rings a bell.



Expansion must be allowed for in steel structures. A long bridge may change in length by many inches when subjected to extreme temperature variations, and expansion joints must be provided. Heat expansion causes clocks and watches to “run slow” by lengthening pendulums and increasing the size of balance wheels. These effects can be suitably compensated.

There are exceptions to the rule that heat causes expansion. The behavior of water is interesting. When cooled from ordinary temperatures it first contracts as expected, and then after reaching 39° begins to *expand* while being further cooled to its freezing point. It's easy to verify this fact. Put some water in a tall jar or bottle and add crushed ice, which of course floats at the top. A thermometer lowered to the bottom of the vessel by a thread soon assumes a steady reading of about 39° , while when drawn slowly up to higher levels, the readings

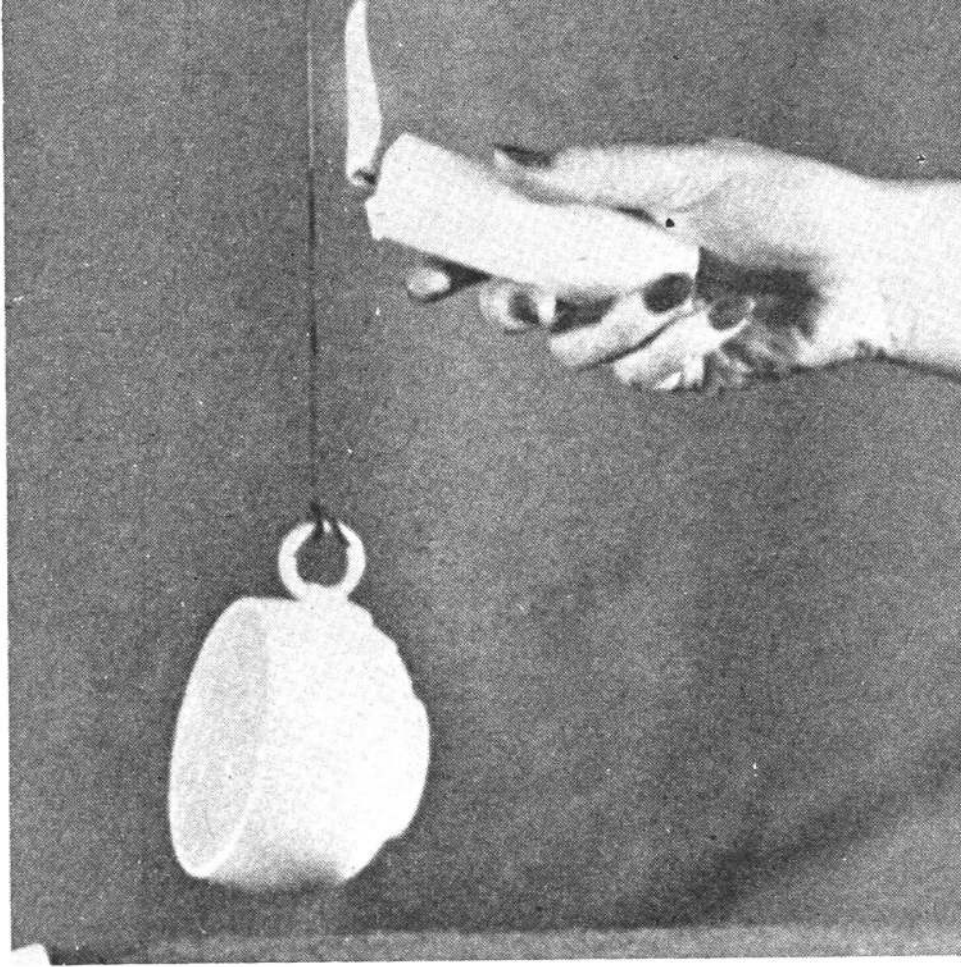
are in succession lower and lower until, when the bulb is surrounded by ice, the indicated temperature is 32° . The fact that the water at 39° sinks to the bottom while cooler liquid floats above it shows that water attains its greatest density—greatest contraction—at this temperature. One consequence is that the fish that spend the winter beneath the frozen surface of a pond have a better time of it than the animals that live on the chill surface of the earth.

Another apparent exception to the expansion rule is rubber. A stretched rubber band contracts when heated. It does so because it has the peculiar ability to become slightly stronger at the higher temperature. Snip a long rubber band in two and tie it to a hook. Attach to its other end a weight that stretches it by about half its original length. Pass a candle flame rapidly up and down the band several times and the weight will be jerked upward. The band returns to about its former length as it cools.

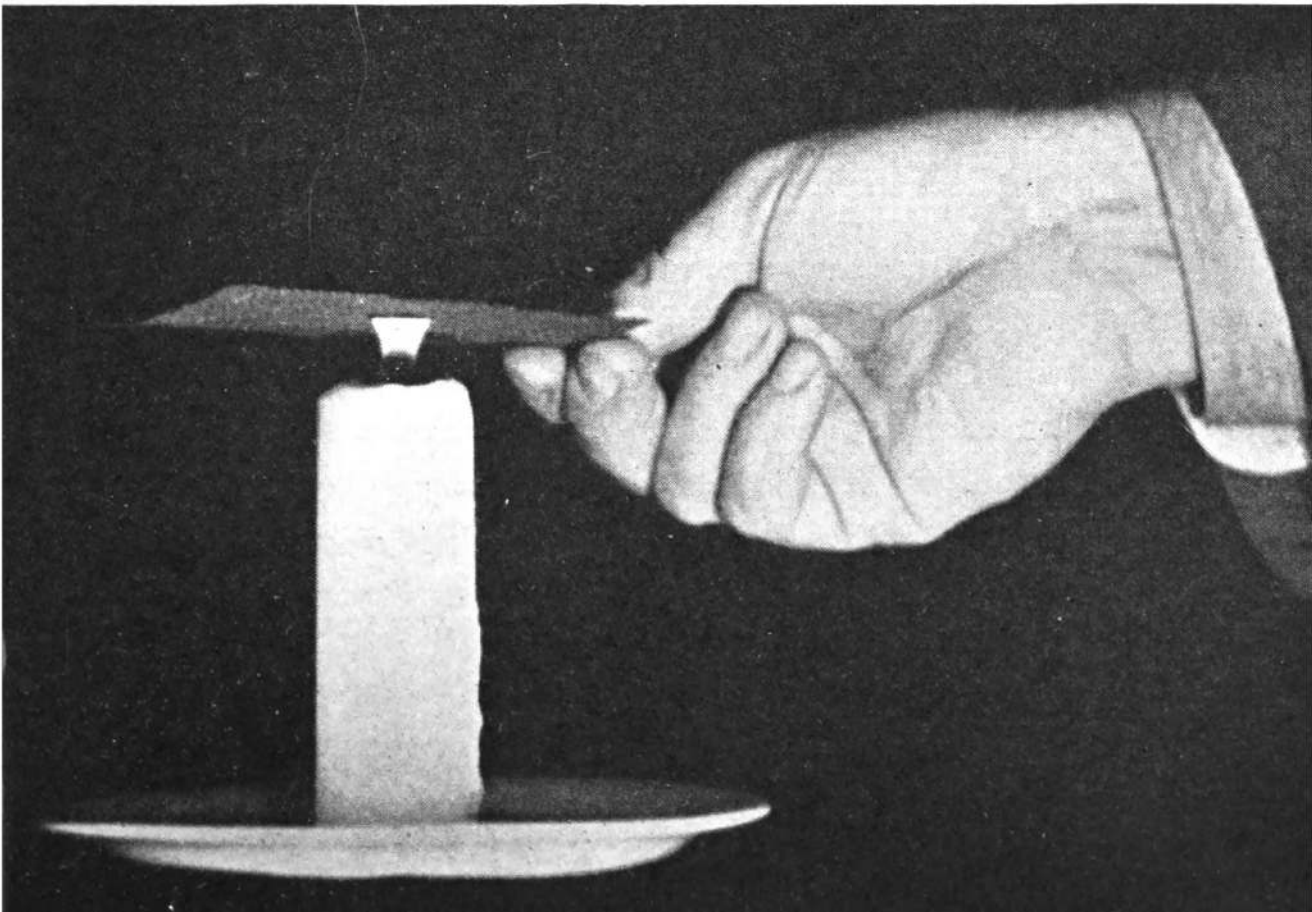
The reverse behavior is also shown by rubber. Hold a rubber band in light contact with your lips and stretch it suddenly. You will feel a marked heating effect. Now let it contract again and you experience a cooling. This is just opposite to the behavior of most other substances.

Suppose you were to pour some water whose temperature is 70° —about room temperature—into an equal amount of water that has been in the refrigerator and is at, say, 40° . If mixed quickly, you would expect a thermometer dipped into the mixture to read 55° , or just half way between the two temperatures. But now tie together a half dozen or so clean iron nails and suspend them in boiling water by a thread. Have ready in the refrigerator a small tin box containing an amount of water weighing about the same as the bundle of nails. Read its temperature. The box of water, previously

*Stretched
rubber is
unique in
contracting
when heated*



Heat conductivity of the wire screen prevents the flame from going through



chilled to say 40° , is now removed and placed on a few thicknesses of newspaper. Remove the nails from the boiling water, lower them quickly, but without splashing, into the chilled water and stir it with a thermometer, reading the highest temperature attained. You will now find that the final temperature of the combination is not at all near 126° , half way between 40° and 212° ; rather, it will be down near 60° . Water has the highest heat capacity of all common substances; iron has only about $1/10$ as much, as this test shows.

The high heat capacity of water is responsible for the reduction of the daily and seasonal temperature variations of island and seacoast localities. When the sun is strong, the ocean takes up a great deal of heat energy but does not change much in temperature in doing so; when the sun is weak, or at night, this heat is given up to the air, preventing the temperature from going as low as it otherwise might.

You can demonstrate to a group of people the ability of a metal to take up and retain heat. Ask each person to put a penny in a felt hat and, after you have left the room, let someone select a coin and pass it around so that the others can examine the date on it for identification. The penny is then thrown back into the hat. Re-entering the room, you reach into the hat and immediately produce the coin that was selected. How is it done? Simply by feeling for the warm penny, which absorbed and retained the heat given to it as it was handled.

Heat travels of its own accord from hot objects to cold ones. A hot stove lid gives up heat to a pan of water placed on it; the monsoon transfers heat from the south to cooler regions; heat is sent by the sun to the planets. There is no such thing, scientifically speaking, as "transferring cold" from one place to another, for cold is merely absence of heat. Heat is a form

of energy—energy of motion of the tiny molecules of which all substances are composed. When you warm up an object, you merely supply more energy to the molecules—make them move more vigorously. When a hot object is put in contact with a cold one, the faster-moving molecules of the former, colliding with the slower molecules of the cold body, transfer some of their motion to them. The hot substance loses energy (drops in temperature), the cold one gains energy (rises in temperature).

All objects in a room are at approximately the same temperature, yet to your hand a doorknob seems much colder than the wall, and the wooden floor seems much colder to bare feet than does a carpet. The difference is in the ability of these substances to transfer heat. Metals are good **conductors** of heat; stone is moderately good; wood, paper, cloth and air are poor conductors. If one end of a poker is held in the fire, the other end soon becomes hot because of the good heat conduction of iron, but you can comfortably hold the poker by its wooden handle—a poor conductor. Demonstrate the heat conducting ability of metals by applying the lighted end of a cigarette to a handkerchief placed over a coin. The cloth will be uninjured, since the metal takes away the heat before it can cause damage. The handkerchief will immediately scorch if the coin is removed. The same phenomenon is shown by wrapping a piece of paper tightly around a wooden pencil equipped with a metal band for holding the eraser, so that part of the paper is over the wood, part over the metal. Hold the arrangement above a lighted match until the paper begins to char. The part of the paper covering the wood will char while the part over the metal band will remain unharmed, protected by its better heat conduction.

Another experiment on similar lines is that of bringing a

piece of wire screen or an old sieve down into a gas or candle flame. The flame is cut off above the screen, since the latter conducts heat away before the gases there can be ignited. In the early years of the last century there were many disastrous gas explosions in the British coal mines, due to the open flames of the miners' lamps. The great chemist, SIR HUMPHRY DAVY, suggested surrounding the lamp with a fine wire screen. It worked.

Air at rest is a very poor heat conductor, and is referred to as a heat **insulator**. Most of the warmth of woolens and furs is a result of the heat insulating ability of the air trapped between the fibers. The walls of refrigerators are filled with cork dust or mineral wool for a similar reason. The best conductors—metals—transfer heat about 20,000 times as readily as air, but the best heat insulator of all is—nothing! In other words, a vacuum. A thermos bottle consists of a double-walled glass flask with the space between pumped clear of air. There is nothing to conduct heat from one side to the other. A certain old lady was much puzzled by the wonderful action of a vacuum bottle. "How in the world," said she, "does it know when to keep things hot and when to keep them cold?"

While still air transfers heat reluctantly, air that can move freely behaves quite differently. The air immediately above a bonfire is warmed and expands. Being lighter than the surrounding air, it rises in the manner of a balloon. Cool air then flows in from all sides to take its place, and soon a continuous circulation is established. This mass movement of heated air is called **convection**. A hot air heating system operates on this principle. So does an automobile cooling system, for convection takes place in liquids as well as gases. Fill a long, narrow glass tube or vial nearly to the top with water. Holding it at

the lower end, warm the upper end gently over a candle flame. The water at this end will soon begin to boil, yet the lower end remains perfectly cool. This is because convection does not occur, since the warmed water remains at the top. Inasmuch as water is a poor conductor, hardly any heat is transferred to the lower end. If you hold the tube near its upper end and warm the bottom, it very soon becomes too hot to hold.

Even more impressive is the trick of boiling water in a paper tray. Fold a quarter of a sheet of letter paper to form a rectangular tray. Hang it by cords attached to the corners, and place some water in it. The water can be brought to a boil by a candle or gas flame placed under the tray, without danger of burning the paper, which is protected by the high heat capacity of water and by its convection motion which enables it to distribute the heat applied locally.

Stand a burning candle in the center of a saucer that contains a little water. Moisten the inner surface of a cardboard mailing tube, so that it will not catch fire, and lower the tube over the candle until its bottom edge is beneath the water surface. Despite the opening at the top, the candle goes out, since no fresh oxygen can get to it by convection. Raise the tube even a sixteenth of an inch above the water and the candle continues to burn, but can be extinguished again by covering the top of the tube with a flat piece of tin.

Explore convection movements of air by holding a lighted match or candle in a shaft of sunlight entering a room. Watch the rapid upward movement of the dust particles above the flame. Another way to trace air currents is with the movement of the flame itself. Open the door of a warm room a fraction of an inch and hold a flame near the crack at the

top of the door. The flame will bend over toward the adjoining cooler room, but when held near the floor will lean over into the warm room.

It's easy to make a convection merry-go-round. Cut a round piece, about three inches in diameter, from a card; then cut inward from the edge on a spiral toward the middle. Push a pin part way through the center of the card and set the point on a tall support—the flat end of a pencil held in a vertical position. The spiral hangs down by its own weight. Enough convection is provided by the upturned palm of your hand, held beneath the spiral, to set it into continuous rotation. It turns much faster when a lighted match is held below, or when the device is placed on a warm radiator.

When you sit before an open fireplace you get a definite sensation of warmth, although heat is certainly not reaching you by convection, since the heated air flows almost straight up the chimney. Conduction through the air is far too small to account for the effect. The heat reaches you by means of another process—**radiation**. This means that the source of heat is sending out waves of the same general nature as light waves—not visible, but noticeable only through the effect of the warmth they produce. Heat radiation, like ordinary visible light, can travel even through empty space; that is how we receive heat and light from the sun and from the distant stars. It is radiation that makes the mountain climber perspire even when the air about him is very cold. The life-giving radiation from the sun travels across 93 million miles of empty space to warm the earth and to supply it with all the varied forms of energy we use on this planet. Think of any source of power you can—it is finally traceable back to the sun: When coal is burned, it merely releases chemical energy which the sun stored up in vegetation millions of years ago.

The falling water that turns a water wheel or turbine has energy only because the sun maintains the great cycle of evaporation whereby water is continually lifted from the lakes and oceans of the globe and later condensed in the form of rain to feed streams and waterfalls. The energy of the wind is a result of convection caused by the sun's rays.

Not only very hot bodies like the sun, but all objects send out radiation to their surroundings. Of course, the lower the body's temperature, the less intense its radiation. Even a cake of ice sends out radiant energy; the reason it feels cool when you place your hand near it is that the ice, being at a lower temperature, sends back to your hand less radiation than it gets from it. There is no such thing as "radiating cold." Place your simple air thermometer (page 106) near a piece of ice or a jar of ice water and see what happens. The thermometer goes down—not because of "cold" sent out by the ice, but because the thermometer itself loses heat by radiating to the cold object.

The amount of energy sent out by a radiating object depends not only on its temperature but on the nature of its surface as well. A hot object having a dark, rough surface sends out more radiation than if it were light-colored and smooth. This may be shown by blackening one of the flat sides of a tin tea or cocoa box and filling it with boiling water. A thermometer held about an inch from the black side will go up much faster than when placed an equal distance from the shiny side. Both sides of the box are at the same temperature, but the dark one sends out radiation at a greater rate.

The reverse is also true: a dark, rough surface *absorbs* more radiant energy than does a light-colored or shiny one. Outdoors in the sunlight, a dark-colored jacket feels warmer than a light-colored one of the same weight. To keep really cool on

a bright summer day, white garments should be worn. Long centuries of experience have taught the Arab that swathing himself in a light-colored burnoose is the best protection against the dazzling desert sun.

Try two experiments on the absorption of radiation: On a white card, make some marks with India ink. Hold the card against a strong electric bulb with the inked side facing the light. The reverse side of the card will soon char directly opposite the ink marks while the white portions remain undamaged. The other test consists in placing two small strips of tin, one shiny and one blackened with India ink or with soot from a candle flame, where direct sunlight can strike them. After several minutes exposure, feel each strip and perceive the difference in temperature due to the much greater rate of absorption by the black surface. The sides of a cooking pot should be highly polished to cut down heat loss by radiation, but the bottom should be black in order to get the most heat in this way from the gas flame beneath.

The temperatures of very hot objects can be found indirectly by measuring the amount of radiation they send out. Delicate electrical detectors of radiation are used for measuring the temperatures of the stars—devices so sensitive that they could detect the heat of a single candle placed a hundred miles away. In this manner the temperatures of some stars are found to be 40,000° Fahrenheit. One star of this kind is found to be pouring radiant energy into space at over 3,000 times the sun's rate.

13

WHEN MOLECULES DANCE

ALTER the temperature of a substance sufficiently and it may change its physical state, as water does when it freezes or when it boils. It was found a long time ago that the temperature at which a substance melts (going from the solid to the liquid state) is the same as that at which it freezes (going from liquid to solid). As you know, water freezes when its temperature is reduced to 32° Fahrenheit and ice melts when its temperature is raised to this same value. You can test this with a thermometer and a refrigerator; or use butter as the material to be melted and solidified, in which case the melting (or freezing) point will be around 90° .

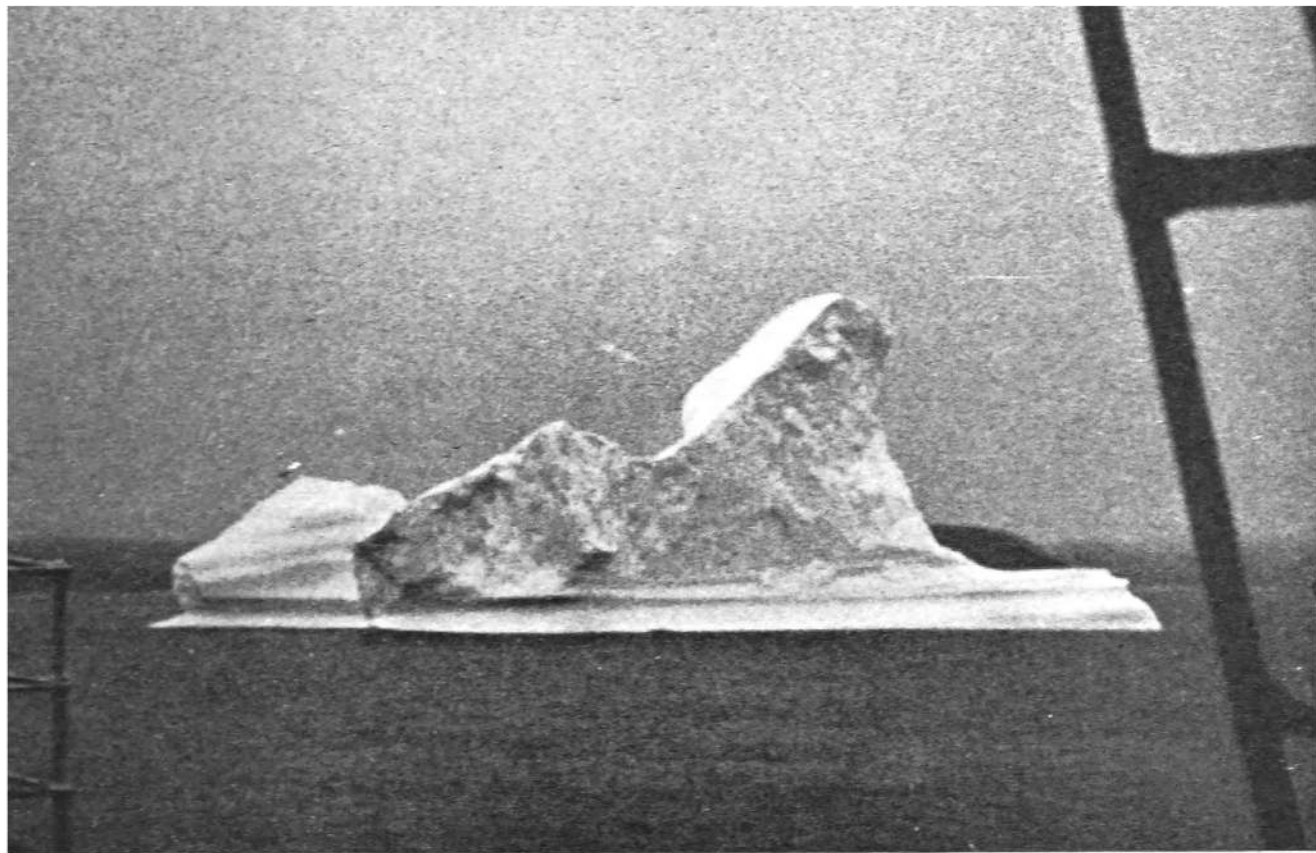
Under given conditions, a given substance always freezes and boils at fixed temperatures. Put a thermometer in a glass of water containing cracked ice and it will settle down to a constant reading of 32° as long as any ice is left, regardless of the temperature of the room. Only when the ice is all gone will the water temperature begin to rise. In the same way, a thermometer in boiling water indicates a steady temperature around 212° . Turning up the flame under an open kettle of pure water will make the water boil away faster, but its temperature will still not exceed 212° as long as there is any water left.

It takes heat to melt ice. A beverage is cooled by ice because the heat required to melt the ice is taken from the surrounding liquid. Equally true, but less well known, is the fact that water *gives up* heat when it freezes; in fact, when a gallon of

water freezes it gives up as much heat as is produced by burning an ounce and a half of good coal. Farmers, storing vegetables in a cellar in winter, make use of this fact by placing large tubs of water about. If the temperature should go below freezing, the water freezes before the fluids (impure water) in the vegetables, and the heat given off is usually sufficient to prevent the temperature of the cellar from going any lower. Compared with other substances, water gives off an unusually great amount of heat on freezing; it is said to have a large **heat of fusion**. That's why, for example, glaciers are able to last through the summer.

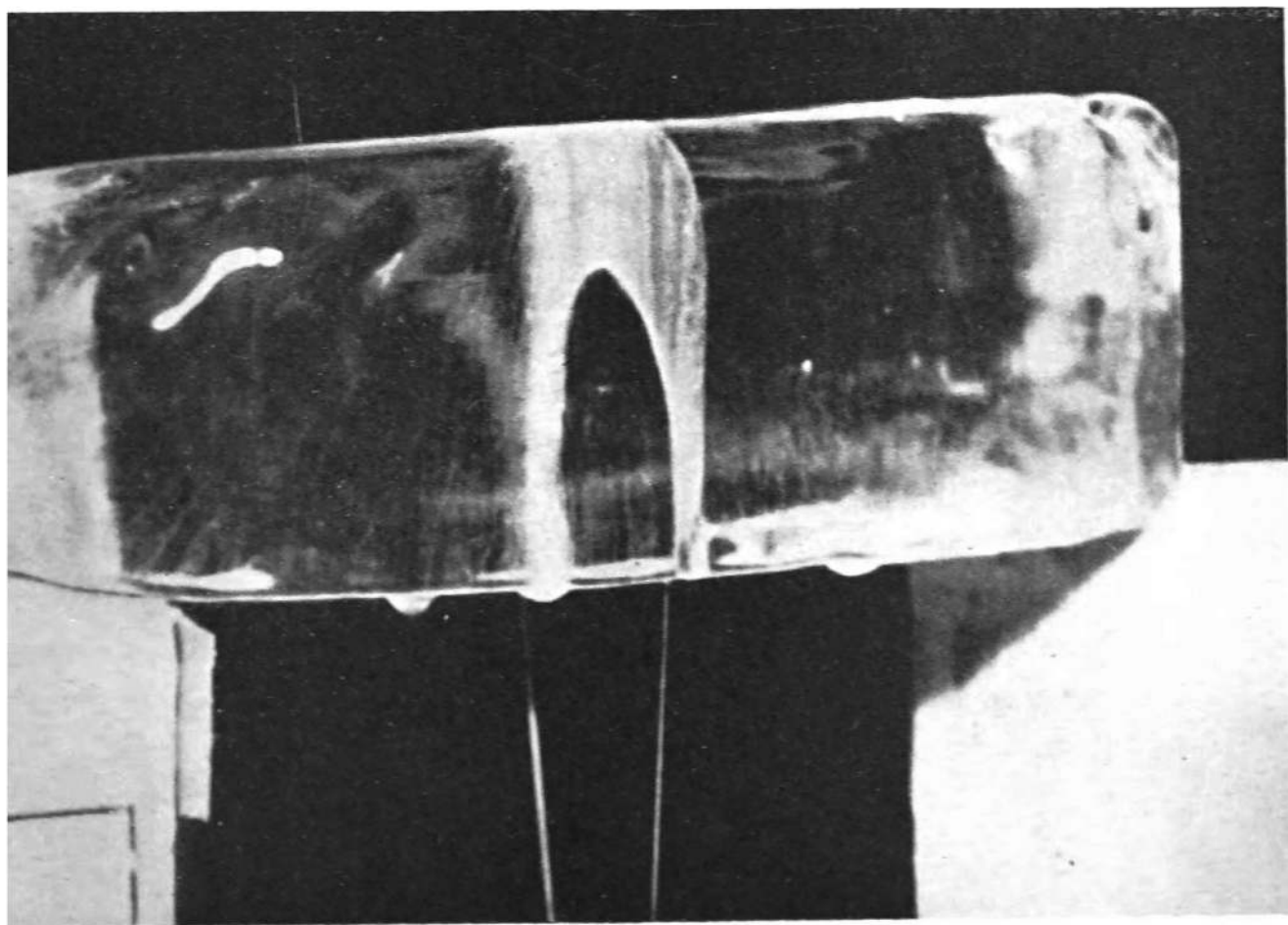
Another fact about freezing that may be more familiar is the sudden and considerable expansion it causes. If you have ever forgotten to take in the milk on a cold morning, you know all about this phenomenon. Water, again, is peculiar in that it expands on freezing, increasing in bulk by about one eleventh. As a result, ice is less dense than water, and so it floats. The force of expansion of freezing water is capable of bursting water pipes and splitting rocks.

While the melting point of ice is ordinarily 32° Fahrenheit, the melting point is lowered when the ice is put under pressure. Secure a rather thick icicle several inches long, or make a bar of ice by removing the dividing partitions from an ice cube tray, filling it with water and placing it in the freezing compartment of the refrigerator. Support the piece of ice at each end and hang over it a loop of bare wire with a brick or other heavy weight attached. Soon the wire will be observed to cut into the ice, as shown in the photograph. After some time it cuts completely through, but leaves the bar intact. The explanation: Under pressure from the wire, the ice goes over into the more compact liquid state, but re-freezes as soon as it flows around to the upper side where the pressure is absent.



There is nine times as much below water

The wire cuts through the block of ice, but leaves it intact



This phenomenon, called **regelation**, also manifests itself when you “pack” a snowball. Try uniting two ice cubes by pressing them together in the hands. What happened to the bar of ice is the same thing that happens when you ice skate. Pressure of the blade melts some ice momentarily; it re-freezes as soon as you pass. You really do not skate directly on ice, but on a thin film of water. Perhaps you have noticed that in extremely cold weather, the skating’s not so good; it’s simply that at such low temperatures the pressure of the blade is insufficient to liquefy the ice.

Reminiscent of making ice cream at an old-fashioned Sunday school picnic is the operation of preparing a freezing mixture: Add a considerable amount of salt to some snow or scraped ice in a tin pan placed on a thick layer of newspaper to insulate it thermally. Stir the mixture, which soon liquefies, with a thermometer. Temperatures as low as six degrees below zero Fahrenheit can be obtained. The freezing point of water is lowered when an impurity—in this case, salt—is present. Rock salt is used to clear pavements and railroad switches of ice in winter.

Up at the boiling point, equally interesting things happen. Heat is required to boil water, whether you watch the kettle or not! A considerable amount of heat, too. It takes about seven times as much heat to vaporize a gallon of boiling water as it does to melt the same bulk of ice. We say that water has an unusually high **heat of vaporization**. It makes no difference if the vaporization takes place at the boiling point or at any lower temperature; whenever a given amount of water is evaporated, a given amount of heat is carried off. It is the evaporation of previously liquefied ammonia gas or other substance in a refrigerator system that produces the desired cooling effect.

Put some water on a large cork and set a watch crystal or a small, shallow tin dish down upon it. Pour a little of some volatile liquid like ether (keep open flames away!) or alcohol into the dish and promote evaporation by vigorous fanning. If the evaporation is rapid enough, sufficient heat will be carried off to turn the water under the dish into snow, or even to freeze the dish and the cork firmly together.

Evaporation takes place from the surface of a liquid at all temperatures, but when bubbles of the vapor form all through the liquid, we say it is boiling. Boiling occurs as soon as the pressure of the vapor becomes equal to the pressure of the surrounding air. At normal air pressure, this happens when the water temperature reaches the familiar 212° , but if the air pressure is lower—say on top of a mountain—water boils at a lower temperature. You can comfortably hold your hand in boiling water atop a high mountain. In order to cook vegetables at great altitudes, pressure cookers must be used. The vapor pressure builds up inside the closed vessel, so that the water can be raised to cooking temperature before it boils off.

Paradoxically, you can make water boil by cooling it! A thin-walled glass flask or bottle is half filled with water, which is brought to a boil. Holding the flask with a towel, remove it from the fire and cork it tightly. Boiling stops at once, but each time some cold water is poured over the bottle, the contained water boils anew. Cooling condenses some of the steam inside the flask, and this lowers the pressure, permitting the hot water to boil despite the fact that its temperature may be far below the normal boiling point. The pressure decrease may even draw the cork into the bottle. Even cold water placed in a vessel from which the air is pumped will begin to boil, as in the last experiment, and heat may be carried away so rapidly by the vapor that the

water finally becomes ice,—an instance of water boiling so hard that it freezes! We already saw that water produces heat when it becomes ice, and that heat is carried away when water boils; so despite the strangeness of the idea, it is true that freezing is a *warming* process and boiling is a *cooling* process. That's something to think about.

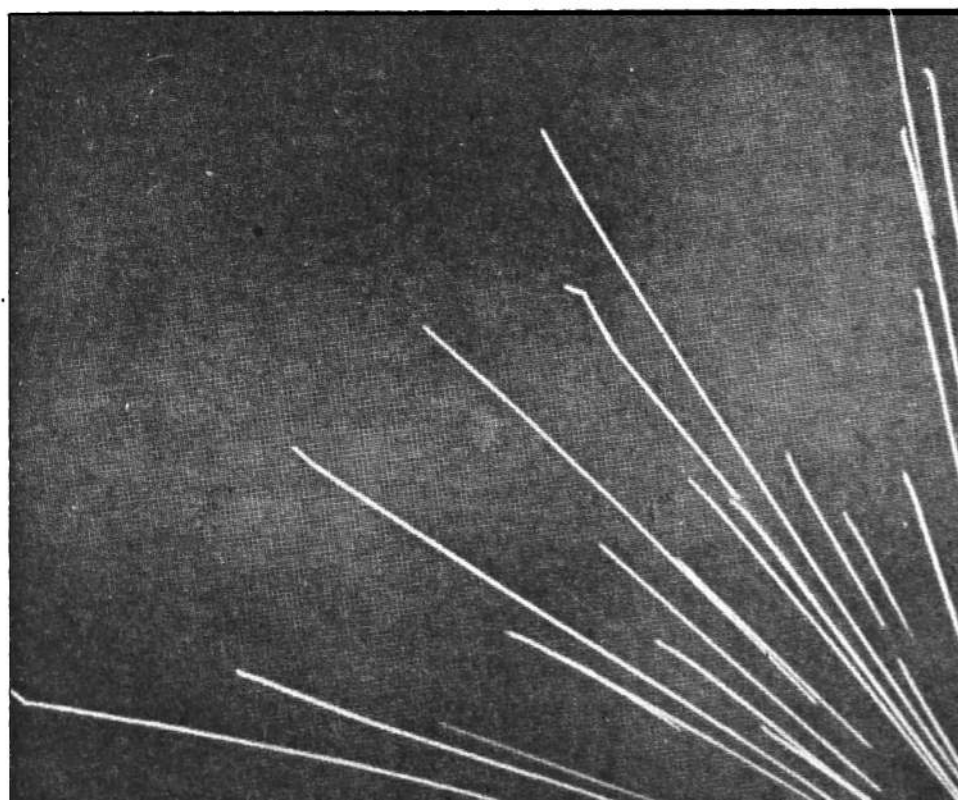
The great play of evaporation and condensation of water in the earth's atmosphere is really one of the most important factors affecting the weather. Indoor weather, too, is concerned with the humidity of the air. One of the functions of air conditioning is to regulate the amount of moisture in the air of homes and public buildings, keeping it to a healthful amount, winter and summer. To measure the **relative humidity** of the air in your home, drop small bits of ice into a tumbler containing water, stirring constantly with a thermometer, until dew just begins to cloud over the outer surface of the glass. Of course, this is vapor condensed from the air, not water that "sweats" through the tumbler. Note the reading of the thermometer when dew forms. The closer this reading is to the temperature of the room, the more moisture there is in the air. For a room at the optimum temperature of 70° , this dew point, as it's called, should be about 52° . This corresponds to a healthful relative humidity of about 60 per cent, which means that the air in the room contains about 60 per cent of the greatest amount of moisture it can possibly hold at that temperature.

You can easily make a **hygroscope**, or humidity indicator, for checking the condition of the air in your home. Remove the oil from a long human hair by soaking it in a little alcohol or ether, or by boiling it in water to which a little washing soda is added. Fasten one end of the hair to a nail driven into a vertical board, the other to a point near the pivot of a card-

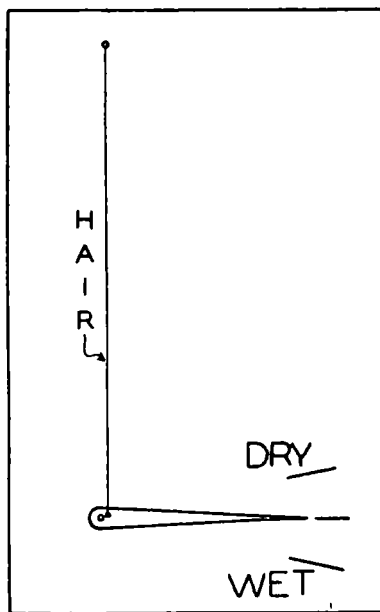


Condensation is imminent

*Condensing
moisture
outlines the
paths of
atom
fragments*



board pointer turning freely on another nail. Increased air humidity causes a slight lengthening of the hair which is magnified by the pointer. Mark the normal point of the instrument by comparing with the relative humidity found by the method of the previous experiment.



It measures humidity

A fog forms when moisture condenses in the air about us, usually due to cooler air mixing with moist air and bringing it down to its dew point. When the condensation takes place at some height above the ground we have clouds. Another way to produce a fog is to cause moist air to expand suddenly. The rapid expansion cools it below its dew point. Pulling a cork briskly out of a cooled beverage bottle often results in the formation of a fog in the neck of the bottle.

Condensation of the water vapor in the air has to start about some center, usually particles of dust or smoke, or tiny electric charges always found floating about. Fogs are generally heavier in dusty cities than in the open country. Intro-

duce some cigarette smoke into a large bottle, then pour in a little alcohol, quickly insert the cork, and shake the bottle vigorously. When you now remove the stopper, the vapor rushes out with a "pop" and the resulting expansion cools the gases to the point where a dense fog forms.

Fogs produced artificially by sudden expansion of the air in a closed vessel are used by atom-smashing researchers to make visible the paths of the electrical particles shot out from exploding atoms. The moisture collects along the path of such a particle, because in rushing across the chamber it breaks up the atoms in its way, and the electrified fragments serve as centers for the formation of visible drops.

When the temperature is low enough, moisture in the air does not liquefy, but goes directly to the solid state in the form of **frost**. If carbon dioxide gas—the gas used in making soda water—is allowed to escape rapidly from a tank, it is chilled so drastically that it becomes carbon dioxide "snow." Compressed into blocks, this solid carbon dioxide is what we call "dry ice." Its temperature is nearly 150° below that of ordinary ice, and as a cooling agent it is much more efficient and convenient.

At the end of the eighteenth century the American-born COUNT RUMFORD, military adviser to the Elector of Bavaria, noticed that when cannon were being bored in an arsenal, the metal became quite hot. This suggested to him that heat is a form of energy appearing in this instance at the expense of the power that turned the drill; as long as mechanical energy was supplied, heat continued to evolve. He even measured the amount of heat developed by causing the hot cannon barrel to warm up a certain quantity of water. Later, JAMES JOULE, an English brewer with a bent for science, measured accurately the quantity of heat developed when a given

amount of mechanical energy is expended. He found that no matter what the particular method used—whether friction, impact, or any other process—a definite relationship exists. To raise the temperature of a gallon of water from the freezing to the boiling point requires the expenditure of an amount of energy that would raise a one-ton weight to the top of a fifty story building.

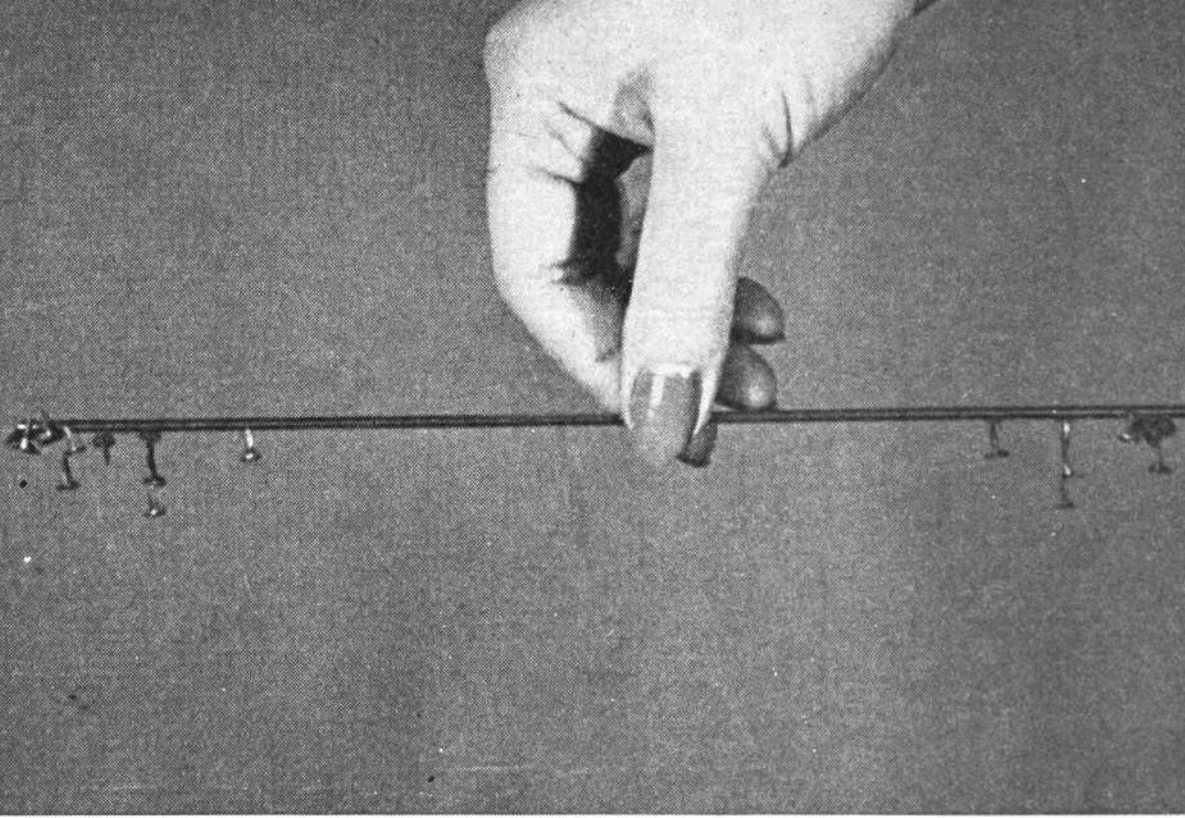
Friction, for example, changes mechanical energy into heat; a steam engine changes heat into mechanical motion. Heat itself is merely motion in another form—the perpetual agitation of the molecules of a substance, moving more slowly at low temperatures, more violently at high temperatures.

JOULE, and independently the German physician ROBERT MAYER, conceived the idea that energy is something indestructible; all that can be done is to *convert* what already exists from one form into another. This great principle, known as the **Conservation of Energy**, is one of the most general and far-reaching in all of science. It is Nature's final and uncompromising answer to those who would get something for nothing.

WHAT STRANGE ATTRACTION

OVER twenty-five centuries ago, the ancient Greeks found that a certain kind of rock had the mysterious power to attract pieces of iron. The Chinese discovered that a splinter of this rock suspended from a thread would always set itself in a north-south line, and they used the device in navigation. But the reason for the strange behavior of these so-called **magnets** remained a puzzle for a very long time. In the Middle Ages it was seriously believed that natural magnets lost their power when rubbed with onions or garlic, regained their potency if smeared with goat's blood! It was not until 1600 that WILLIAM GILBERT, Queen Elizabeth's physician, gathered the scientific facts about magnetism and published them, together with his own careful experimental findings.

You can work out many of the important facts about magnetism with the aid of a small steel horse-shoe magnet that can be gotten in any toy shop or ten cent store. Now make a bar magnet out of a steel file or knitting needle by stroking it repeatedly with one end of the horse-shoe magnet, always moving the latter along the needle in one direction and making the return trip some inches away. The needle, previously an unmagnetized piece of steel, will now pick up carpet tacks, which will cling best to two points, one near each end of the bar, but not to the middle. The two points where the magnetic force seems to be concentrated are called the **poles** of the magnet. There is one near each end of the horse-shoe magnet, too, as revealed by dipping it into a box of tacks.



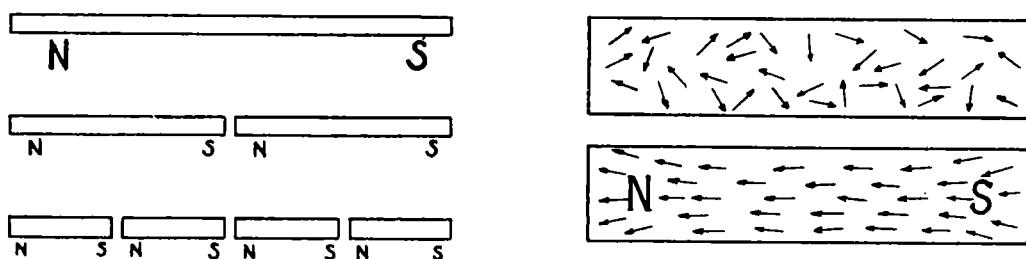
A knitting needle becomes a magnet

Suspend the magnetized bar by a piece of silk thread so that it hangs level and turns freely. Invariably it is found to take a roughly north and south position in coming to rest. The bar is, in fact, a compass. The pole at the north-pointing end of the bar is called a north magnet pole, or simply N pole; the other is the south, or S pole.

Bring an unmagnetized piece of iron—a nail—first near one end and then near the other of a suspended compass needle. Both ends of the needle are attracted. Things are otherwise when, in place of a nail, you bring one end of a magnetized needle up to the compass. An S pole will attract an N pole, but two N poles or two S poles will *repel*—actually drive each other away. We summarize this behavior by saying that *like* poles *repel* each other, *unlike* poles *attract*.

If a bar magnet is cut in two, it is found that a new pole now exists at each cut end, opposite in kind to the pole at the other end of the piece. No matter how many times the cut-

ting process is carried out, this is found to be the case. It is quite impossible to get a piece of steel with only one pole—they always occur in pairs. This suggests that when the ultimate step in the cutting-up process is reached, you'd still find each piece a diminutive bar magnet having two poles. In fact, if we make the assumption that magnetic materials are composed of tiny, individual magnetic units, we can explain many things. In an unmagnetized piece of iron, these entities



*Each piece of a severed magnet
has two poles*

*Magnetization is merely a lining-
up process*

are arranged in a helter-skelter fashion, lying in all possible directions. When you magnetize the bar—for example, by stroking with a magnet—you line up these little magnets all in one general direction. The poles of the bar represent merely the net effect of these myriad little magnets. Heat a magnet red hot and it is found to be a magnet no longer after it has cooled: the jostling of the molecules, frenzied by their extra heat energy, has knocked the tiny magnets out of their orderly array. Only a relatively small number of substances seem to possess these magnetic entities: Iron, nickel, cobalt and some recently developed alloys containing other metals are the only materials of which magnets can be made.

A steel magnet will pick up several brads or tacks, chain fashion. Carefully take hold of the top tack and remove the magnet. The chain at once goes to pieces; the top tack at-

tracted the one below it, and this in turn attracted the next, but only as long as the magnet was near. We say that magnetism was **induced** in the tacks by the permanent magnet. They were magnetic only while the bar magnet was there to keep the elementary magnets lined up; as soon as it "turned its back," chaos reigned. Iron, we say, makes a **temporary** magnet, while steel (iron containing carbon) becomes a **permanent** magnet, like the knitting needles or the toy magnet. Soft iron cores form the indispensable temporary magnets used in electric doorbells, telegraph instruments, telephones, radio sets, etc.

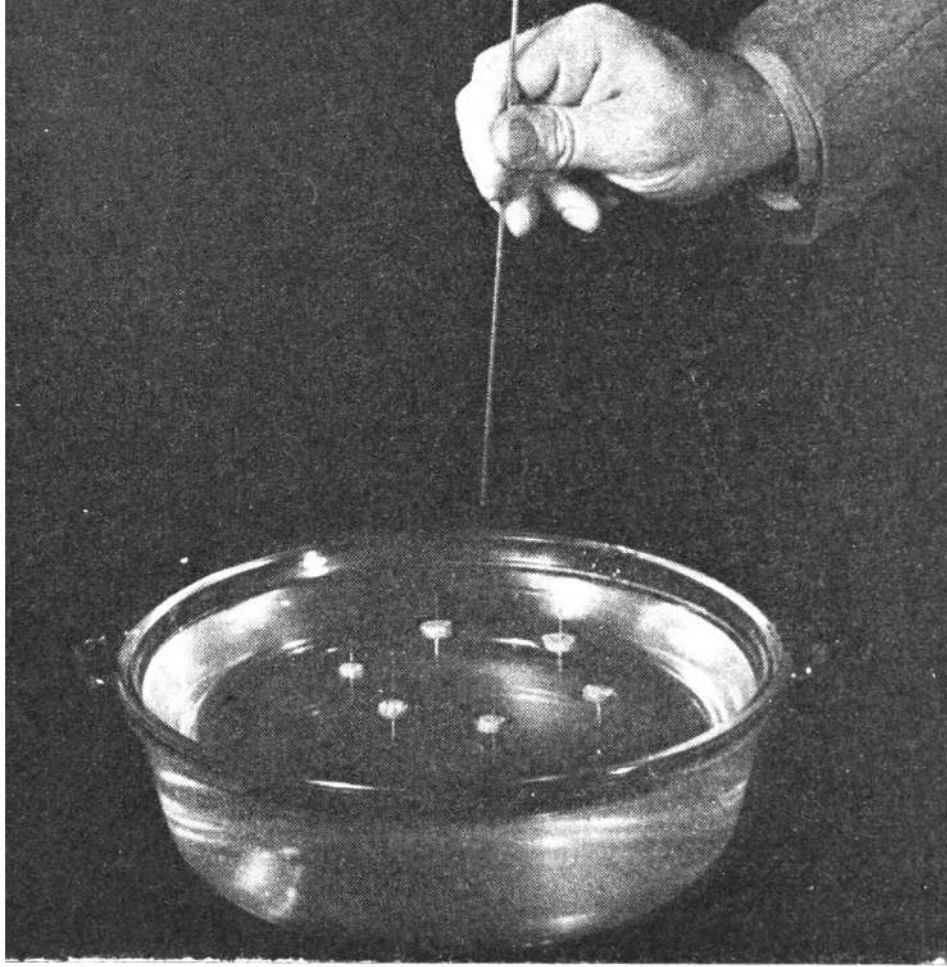
One of the most remarkable things about magnetic force is its ability to act at a distance. A nail can be made to move about mysteriously on the table by means of a magnet concealed underneath, but if the table top is thick, the magnetic attraction may be too weak to move the nail. The force between two magnet poles or between a magnet pole and a small piece of unmagnetized iron falls off very rapidly as the distance apart is increased. In reality, it decreases in the same general way as gravitational force (page 51).

A "ballet dance" of floating magnets illustrates the forces acting between magnets. Take a number of sewing needles and magnetize them all at one time by stroking with one end of a horse-shoe magnet. Thrust each needle through a small piece of cork and float them upright in water with, say, all N poles upward. Setting them in a row, bring near to the group from above the S pole of a magnetized bar or knitting needle. At once the floating needles arrange themselves to form a perfectly regular many-sided figure—a hexagon if there are six of them. If now the bar magnet is turned about, the needles scurry apart, but return promptly when the magnet is again reversed. This *corps de ballet* will execute even

the intricate movements of the quadrille if, before repeating the experiment, every second needle is turned about so that its S pole is uppermost.

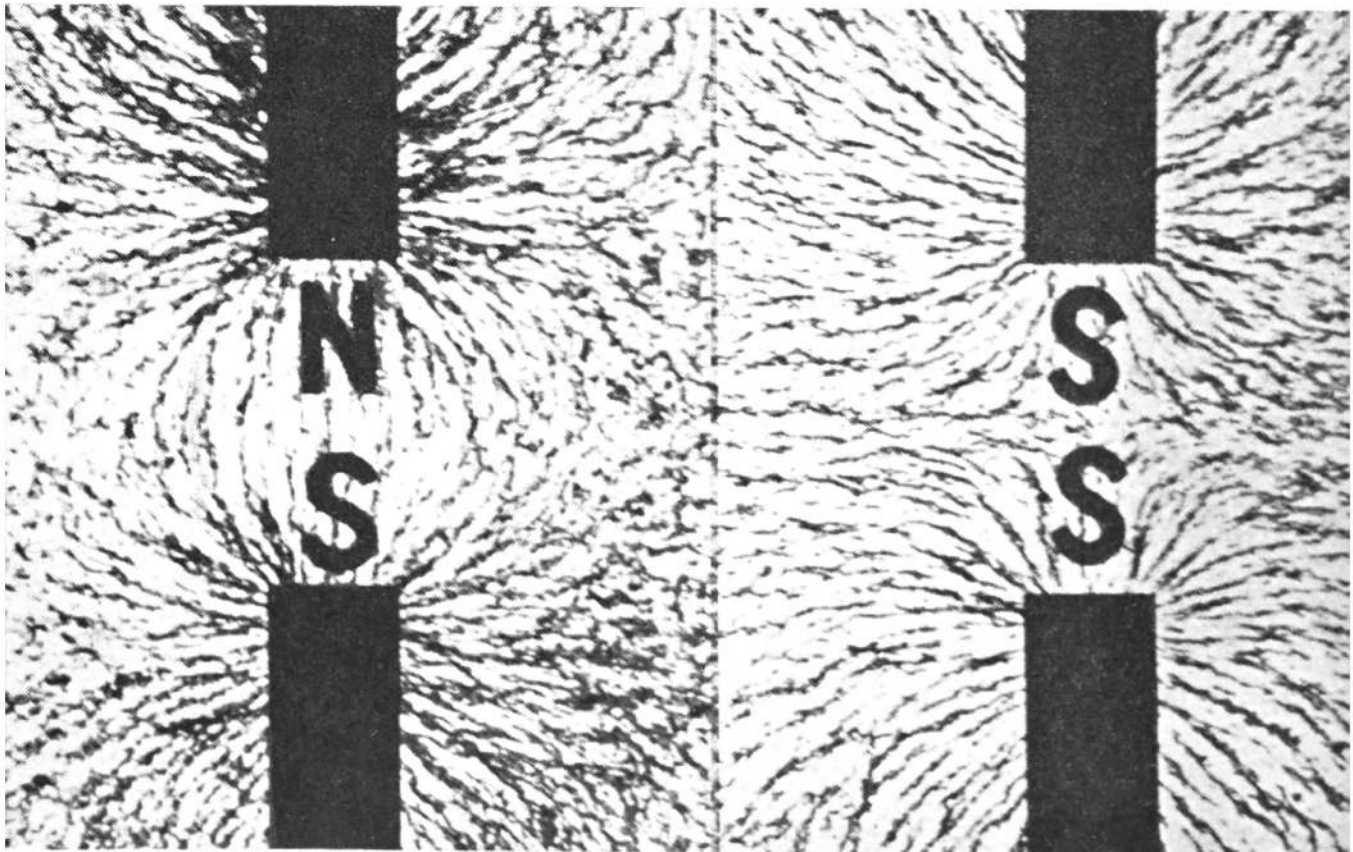
Place a bar magnet upon a large sheet of paper or cardboard. Set a small pocket compass down upon the paper just beyond one end of the bar and mark the direction in which the compass needle comes to rest by means of a short, pencilled arrow. Move the compass onward a short distance in the direction of the arrow and mark the position again. Repeat this process, and you will have a series of arrows going along a smooth curve from one pole to the other of the bar magnet. The great electrical genius, MICHAEL FARADAY, found it helpful to imagine the space about any magnet to be mapped out by such **lines of magnetic force**, as he called them. An easy way of making an entire set of lines of force visible at one time is to strew or sift iron filings onto a large card placed on top of a magnet or group of magnets. The bits of iron arrange themselves along the lines of force, as shown in the pictures. In reality, other similar lines of force must be imagined extending out in space above and below the surface of the page as well as in the plane of the figure.

FARADAY found that he could more easily remember how magnets behave if he assumed that these lines of force, while purely imaginary (like lines of latitude and longitude on the earth), act like stiffened rubber bands. For example, the picture shows that the lines of force between two magnet poles of opposite kind go across from one pole to the other; if they were really stretched rubber bands, the poles would tend to pull together, which is actually the case. For two poles of the same kind, the lines bend away from each other, and if they are assumed to behave like stiffened fibers, this would account for the fact that the two poles tend to push apart.

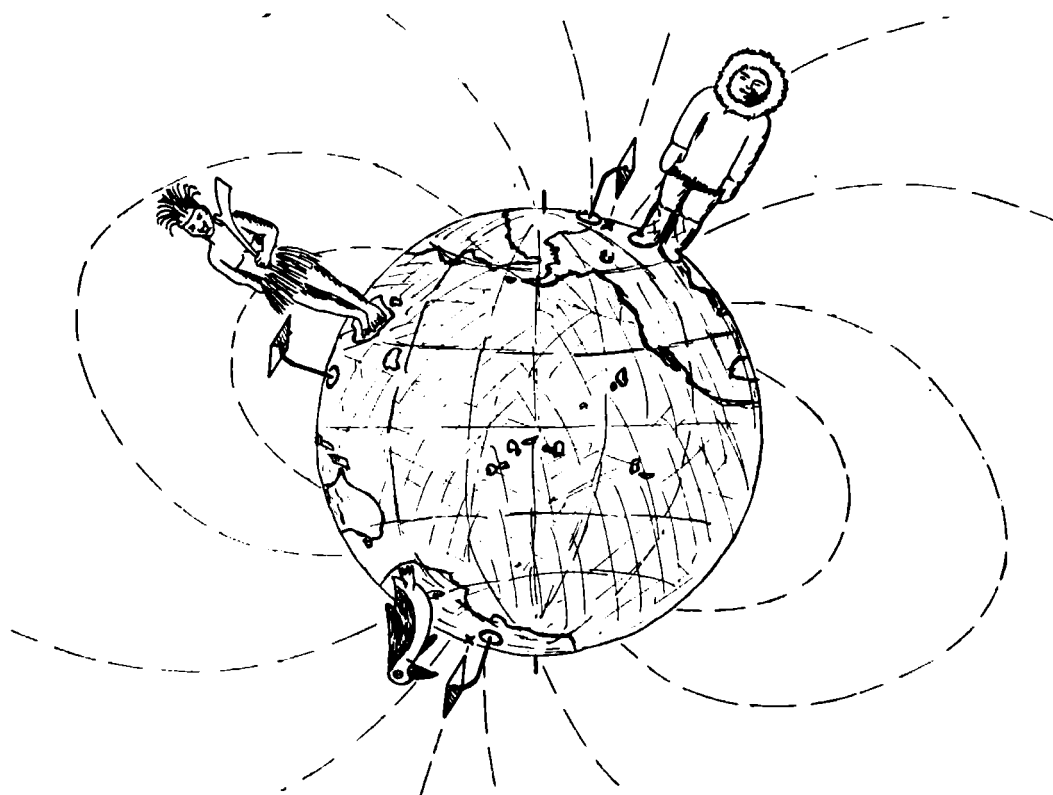


*The
magnetized
knitting needle
directs the
movements
of the ballet*

Bits of iron arrange themselves along the lines of magnetic force



A compass points to the north because the earth is itself a tremendous magnet. What causes this magnetism is not clear. The greater part of it seems to be due to magnetic material inside the earth's core, and the rotation of the earth may have



You're living on a huge magnet

something to do with its magnetism. GILBERT shaped a ball of magnetic rock and found it to be surrounded by lines of force much like those about the earth.

Set a stick on top of a post so that it lies parallel to the compass needle, and you'll find by sighting along this line at distant objects that it is not exactly in the true north-south direction. The compass-indicated north differs in most localities from true north. In the eastern part of our country, the **declination** is over 20 degrees west of true north, while in the northwest, the magnetic needle points about this much east-

ward. Columbus's greatest discovery was not America, but his finding that the compass was subject to such errors. Navigators of today, equipped with charts showing the declination values, can use the magnetic compass with confidence.

If a magnetized knitting needle is suspended from its exact middle, it will come to rest with its north end sloping downward at a rather steep angle, which means that the lines of force at the place in question have this direction. The **angle of dip**, as it is called, varies from nearly 60 degrees in Florida to almost 80 degrees in North Dakota. In the southern hemisphere, the north pole of a compass points upward. There are two places on the earth's surface where the dip angle is 90 degrees—where the needle points straight down or straight up. These are called the **magnetic poles** of the earth. One is located north of Hudson Bay, and is over a thousand miles from the geographical north pole. At points between these two north poles, the compass points south! The other magnetic pole is on the opposite side of the globe, in the Antarctic.

An unmagnetized piece of iron (not steel) held parallel to the direction taken by a dip needle and hit a sharp blow by a hammer is subsequently found to be a weak magnet when tested by bringing its ends near a compass needle. The blow momentarily releases the elementary magnets from the forces that hold them, permitting the earth's lines of force partially to line them up in the direction of the bar.

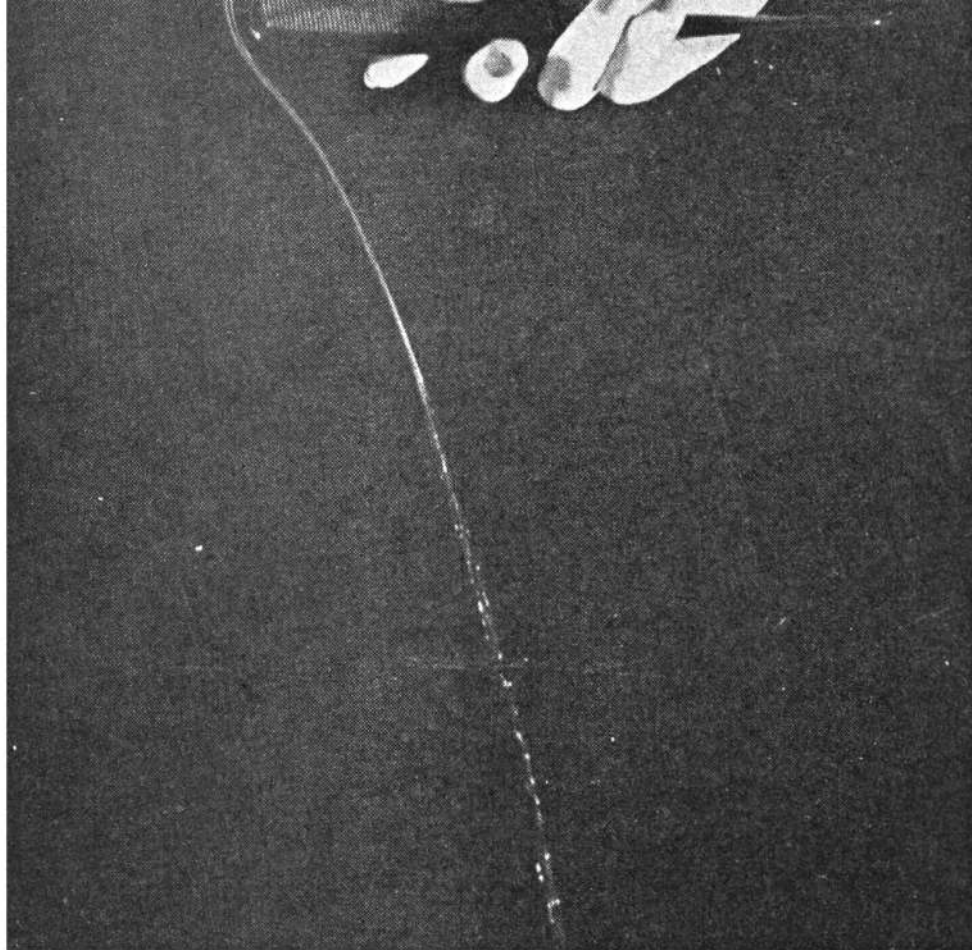
Being humans, we are usually curious about how the forces of Nature affect us. As far as magnetism is concerned, there is no definite evidence that this force has any effect on any form of living matter. In spite of this widely-known fact, thousands of alleged "magnetic health belts" and "magnetic healing pads" are sold each year to gullible citizens of this otherwise enlightened land.

ELECTRICITY AT REST

IN ancient Greece, two brothers were born—brothers strangely alike, yet subtly different in character. For over 2200 years they went their separate ways; they were not even suspected of being related. Finally they met, recognized their family ties, and set out upon a grand program of co-operation that did much to enable man to triumph over Nature and free himself from slavery. We have already become acquainted with one of these brothers. His name is Magnetism. The other is known as Electricity.

The philosopher THALES was probably one of the first mortals to notice that a piece of amber, when rubbed with fur, acquired the ability to attract and pick up light objects like feathers or bits of wood. As in the history of magnetism, nothing further of importance was discovered until the time of Shakespeare, when GILBERT found that many other things besides amber had the same power. He gave a name to the phenomenon—**electrification**—derived from the Greek word for amber.

Today, everybody is familiar with frictional electricity. Who has not noticed the crackling noise and even visible sparks—thunder and lightning in miniature—that result when you shake hands with a friend after walking across a thick woolen carpet? Another experiment consists in placing a sheet of paper on top of a stove or radiator to dry it thoroughly, after which it is placed against a wall and rubbed with a woolen cloth. The paper becomes so strongly electri-



*A rubbed
comb attracts
a stream of
water*

fied that it sticks to the wall; when pulled away, crackling sparks are produced that are visible in the dark. Run a comb through your hair several times and bring it up edgewise to within half an inch of a fine, steady stream of water from a faucet. When the comb comes close, the attraction pulls the stream sharply off to the side, as pictured here. All of these frictional electricity phenomena operate best in dry weather; moisture—even an invisible film of it—permits the electric charge to leak away.

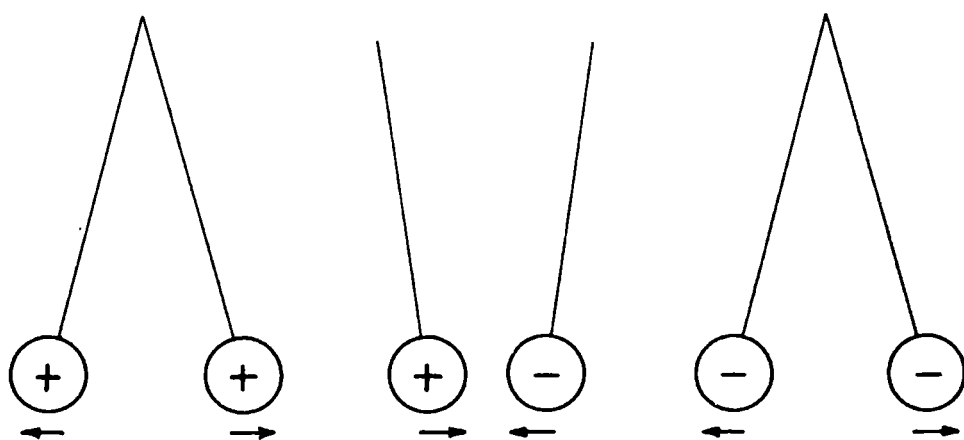
We can repeat many of the experiments of the pioneer investigators and recapture the supreme thrills which must have been theirs when they searched out the facts of electricity for the first time; for electricity it is that makes small objects stick to an amber rod—the same agency that runs the motors, actuates the telephones, lights the homes and fac-

tories of our modern age. The only difference is that the electricity on an amber rod or rubber comb is at rest—**static electricity**—while that used in engineering is in motion.

The first thing to do in the study of electricity is to cut a ball about half an inch in diameter out of a well-dried potato! Cover it with a piece of light tinfoil (chewing gum wrapper, for instance) and hang it by means of a foot or so of silk thread. This is a simple **electroscope**, or detector of electricity. Hold a hard rubber comb or fountain pen or a stick of sealing wax at one end and rub it vigorously several times on a woolen coat sleeve, or with a piece of chamois skin or fur. Bring the pen or stick of wax close to the suspended ball and note that it is strongly attracted. If you allow the two to touch, the attraction at once changes to repulsion. Now repeat the procedure, substituting for sealing wax rubbed with fur a rod or tube of glass that has been rubbed with a piece of silk cloth. Again the ball is attracted, only to be repelled once the rod and ball are allowed to come in contact. Finally, touch the ball with the rubbed wax or fountain pen, then bring up the glass rod that was rubbed with silk. This time, there's attraction. If the two are not allowed to touch, and you now bring the pen close up again, repulsion results. Exactly the same things happen if the pen and glass rod are interchanged throughout the last set of experiments.

All of this may sound rather complicated, but if we merely make the assumption that there are *two* kinds of electrification, the results can be simply stated. In order to distinguish the two kinds of electricity, BENJAMIN FRANKLIN termed the kind on a glass rod **positive** (+), while the kind obtainable from amber or hard rubber he called **negative** (—). Then we can make the general rule (this will remind you of magnetism): Objects carrying the *same* kind of charge *repel*, while

those with *unlike* kinds *attract*. And there you have the whole thing in one simple statement.



Like charges repel; unlike attract

There's a temptation to let it go at that, and pass on to the next item, but this is something so important and so fundamental that you'll find it a good idea to repeat the last experiments at this point, observing how this simple specification of the rule covers all cases.

One of the first to suspect this dual nature of electricity was ROBERT SYMMER, who lived in the eighteenth century. He was accustomed to wearing two pairs of stockings at one time—a white woolen pair and over these a black silk pair. On removing both stockings together from one foot and pulling the woolen one out from within the silk, he found that both rounded out of their own accord to reproduce the shape of the foot, and that they showed attractions and repulsions even when many inches apart. In his own words:

“When this experiment is performed with two black stockings in one hand and two white in the other, it exhibits a very curious spectacle; the repulsion of those of the same colour, and the attraction of those of different colours, throws them

into an agitation that is not unentertaining, and makes them catch each at that of its opposite colour, and at a greater distance than one would expect. When allowed to come together they all unite in one mass. When separated, they resume their former appearance, and admit of the repetition of the experiment as often as you please, till their electricity, gradually wasting, stands in need of being recruited."

Here's a comical but instructive experiment that will make your hair stand on end, or at least electrify you: Take half an egg shell, punch a fine hole in the bottom so that water placed in it barely drips out, and hold it in your left hand, with two fingers partly in the water. Seat yourself on a stool having rubber tipped legs, or set each leg in a thick tumbler to prevent electric charge from leaking away. Keep your feet off the floor by resting them on a rung of the stool. Holding a piece of fur or a woolen scarf in the right hand, whip it repeatedly against a nearby table. Since you are insulated from the surroundings, the charge generated in this way will electrify not only your body but also the water in the egg shell, which at once begins to run out in a fine stream. The mutual repulsion of the similar-charged drops makes the stream spread into a cone as it emerges.

Back to childhood for the next venture which begins by cutting a few paper dolls about three-quarters of an inch high out of tissue paper. These dolls are going to dance, so a phonograph record is needed. Rub the record briskly with a piece of fur, lay the dolls upon it, and support firmly about an inch above it a piece of window glass or a plate glass held in place by books. Rub the glass with a piece of silk cloth and observe the response of the dolls: They stand erect and begin to dance up and down between the two surfaces as they are attracted first by the glass, where they take on some of its

charge, and are then immediately repelled by it to the record, and so on. The dance will continue for some time.

After this diversion, perhaps you can take some heavier information about the nature of electricity. It was found out much later on in the study of science that the atoms of which matter is composed are in turn made up of nothing but bits of positive and negative electricity. These ultimate (as far as we now know) units are called, respectively, **protons** and **electrons**. More recently, a third constituent of atoms was discovered. It is an unelectrified bit of matter called a **neutron**.

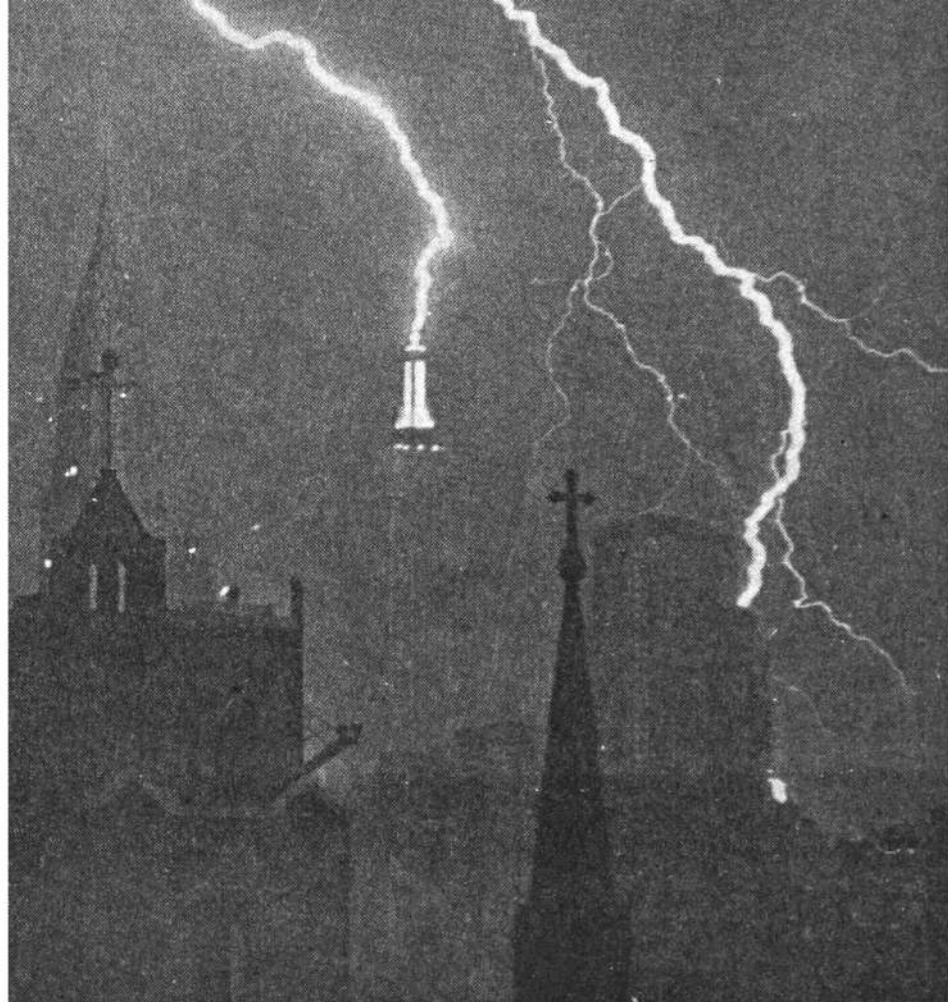
When you rub two unsimilar substances together, here's what happens: The atoms that compose one substance can part more readily with electrons than can the atoms of the other. The result is that when put into good contact—that's the purpose of the rubbing—there's a transfer of some electrons from one to the other. The object that gains electrons becomes, as we have been saying, negatively charged, while the other—which originally had an equal number of protons and electrons, and so was electrically neutral—now lacks these electrons, and is positively charged. You see, a deficiency of negative charge is equivalent to an excess of positive. It happens that the electrons are able to move about more readily than the protons, which nearly always "stay put."

According to this, when a piece of glass becomes positively charged by rubbing with silk, it should be equally true that the silk gets the same quantity of negative charge in the process. You can show at least that the silk and rod are oppositely charged after rubbing by bringing one and then the other near the charged electroscope ball, observing its attraction for one and its repulsion for the other.

A charged object will gradually lose its electricity to the surroundings. If the charge is to remain a long time, the

charged body must be supported on something that does not allow electrons to pass freely along it. Such substances as glass, hard rubber, sulphur, porcelain are suitable. They're called electrical **insulators** or **non-conductors**. On the other hand, many materials, especially metals, allow electrons to pass readily. Such substances are **conductors** of electricity. Even air, particularly moist air, conducts some electricity, and under storm conditions it occasionally breaks down, allowing a charge of electricity to pass violently through it. The conductivity of the air is due mainly to atoms of oxygen and nitrogen from which electrons have been split off. These atoms, which then have a positive charge, are called **ions**. Such ions are produced, for example, in a flame, so that if you hold an electrified piece of hard rubber or glass in the warm air rising from a flame, it is soon discharged by the ions and loses its power to attract light objects. Test this by repeating the experiment on swerving aside a stream of water (page 138), then hold the comb a few inches above a candle flame for several seconds, after which it is no longer capable of deflecting the stream.

When a conductor is charged, the entire charge goes to the outside surface, and none can be found within. That's because each bit of the charge is repelled by all the rest, and they try to get as far away from each other as possible. FARADAY, testing this, took an electroscope, climbed into a large box covered with tinfoil, and allowed an assistant to electrify the cage strongly. No effect was felt by the scientist within, and the electroscope he held in his hand remained still. Here's the same experiment on a smaller scale for you to try: Fasten a few narrow strips of tissue paper to the inside and to the outside surfaces of a sieve supported on dry glasses. Charge the sieve by touching it repeatedly with a rubbed comb and



Courtesy Dr. K. Winfield Ney

*The energy
equivalent
of a billion
rubbed
combs*

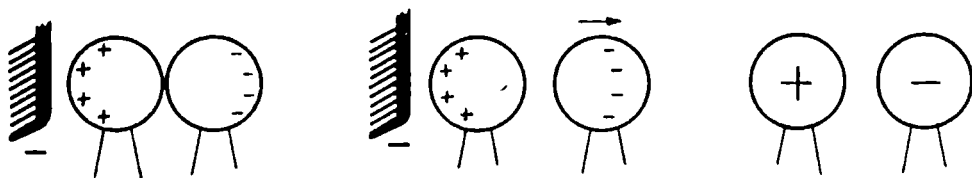
observe that the strips on the outside stand apart, while the inner ones are unaffected. We can conclude that a caged lion in the zoo is safer during an electrical storm than his uncaged companion roaming the African veldt.

Any sheet of metal or wire netting that is **grounded** (connected to the earth or to any large body) acts as an electrical screen, cutting off the effects of a charge placed beyond. That is why radio reception inside a steel-framed building is poor unless you have an aerial on the roof. Insulating substances show no such screening effect.

If a charge is put on an irregular conductor, the tendency of each bit of charge to “get away from it all” causes most of the charge to pile up at the places where the surface is most sharply curved. An egg-shaped body, for example, will have

more charge per square inch at its point than at the round end. And if you go the whole way and put a sharp point on the conductor, the charge may actually leak off at that place. This is the principle of the lightning rod, invented by the versatile BENJAMIN FRANKLIN, whose famous kite experiment showed that the charges brought down from the clouds have the same behavior as static electricity. A lightning rod is merely a pointed conductor placed atop a building and joined by a heavy wire to a metal plate buried in moist earth. Suppose a positive charged cloud is over the building. By attraction, it causes electrons to flow up to the rod from that great reservoir of electricity, the earth. But as soon as this charge reaches the point it discharges through the air to the cloud, quietly neutralizing its charge before a dangerous flash-over can occur.

Secure two small cans or metal boxes and fix each one to the top of a bottle by means of a drop of sealing wax or glue. Placing the two cans on their insulating supports in contact, bring a charged comb near the end of one, but not so close that a spark jumps. Keeping the comb near, move the other can away, being careful to touch only the supporting bottles, not the cans themselves. Now if each in turn is brought near

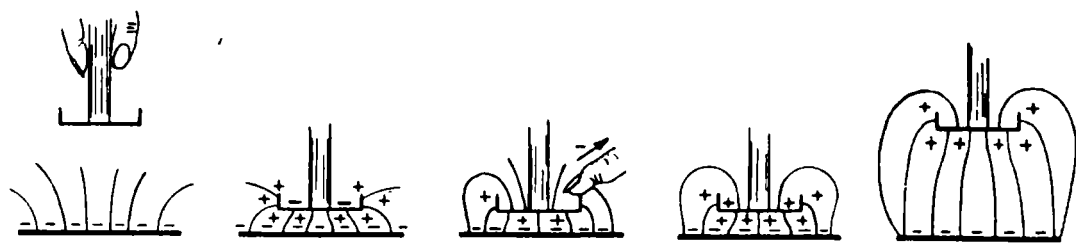


A rubbed comb becomes a magic electrical wand

the previously charged ball electroscope, there will be repulsion in one case and attraction in the other. Using the familiar rule, you will find the can that was nearest the comb before they were separated is positive-charged while the other is neg-

ative. Well, here we have the result that two objects acquire charges without having actually touched a charged body. It is reminiscent of what happens in magnetism: A piece of iron placed in the neighborhood of a steel magnet becomes magnetic by induction. And here, in the electrical case, we speak of **electrostatic induction**. What happened is this: Under the influence of the nearby negative-charged comb, many of the electrons in the metal were driven away to the more remote can, leaving the nearer one positive. If the comb had been taken away at this stage, the electrons would have gone back, leaving both cans again neutral. However, by separating the two while the comb remained near, each can retained its charge.

Using the idea of induction, you can make a “high-powered” generator of electric charge, called an **electrophorus**. Procure a flat metal disc or plate, such as the top of a coffee can, and melt the end of a stick of sealing wax to the middle of the plate to serve as an insulating handle. Place an old phonograph record on the table and rub it briskly with a piece of fur or wool until it crackles. Set the plate on the record, touch the plate momentarily with your finger to “ground” it, and you will find that it has a considerable amount of positive charge after being lifted away by its handle—enough to jump a quarter of an inch or more through the air to your knuckle. The diagram shows the several stages in the process of charging the plate by induction. Without rub-



A simple source of electricity

*From it,
flashes of
lightning
ten feet
long*



Courtesy Mass. Institute of Technology

bing the record again, you can repeat the charging process over and over, getting a fresh charge on the disc each time, until the original charge on the record has leaked away. You “pay” for this apparently unlimited electricity by the work you do every time you lift the disc away against the attraction of the charge on the record. Continuous-operating machines based on the same general principle as this electrophorus produce large amounts of charge at millions of volts. They are used for such purposes as studying the effect of lightning on power lines and for smashing atoms.

With the electrophorus available, you can produce an electrical windstorm. Stand a tin can on a dry tumbler and lay a sewing needle on top of it, with the point projecting out over the edge about an inch. Lay a small weight on the part of the needle in contact with the top of the can if necessary, and be sure it is in contact with a clean portion of the metal. If, now, the can is strongly charged by touching it repeatedly with the electrophorus disc, you will be able to feel a slight air current from the tip of the needle, and this wind may even blow a nearby match flame aside. The discharging effect of the point electrifies—ionizes—the nearby air molecules and dust particles, and they stream away because of mutual repulsion of like charges. The same idea is the basis of the electrical smoke and dust precipitator. The discharge from a set of sharp points within the chimney of a factory electrifies the dust and smoke particles and they drift to an oppositely-charged plate where they are collected. Not only is pollution of the air avoided, but the reclaiming of valuable materials from the dust often pays many times over for the cost of operation of the collector.

Ionization of the air furnishes the means of detecting and measuring the elusive **cosmic rays** that come into the earth's atmosphere from the depths of outer space. This radiation seems to consist of incredibly swift-moving particles rather than waves like X-rays. The atom fragments they produce in their destructive dash through the atmosphere can be made to ionize the air in a special chamber, and the event is recorded by a sensitive electrical detecting mechanism.

Fortunately for those of us who would learn the ways of Nature, the old lady has truly a "one-track mind." A case in point is the attraction or repulsion between two electrically charged bodies. How does the actual amount of the force depend on their distance apart? Experiment shows that the

dependence is the same in this case as we found it to be for magnetic and gravitational forces (pages 132, 51): Double the distance and the force is quartered, treble the distance and it becomes one-ninth as much, and so on. Truly a remarkable unity in these forces that act at a distance!

But don't conclude that gravitation, magnetism, electrostatics are all the same thing; it's not so. Attempts have been made to "explain" gravitation in terms of electricity and magnetism, but without success. And we know that, on the face of it, there are important differences between these phenomena. Gravitational force is always one of attraction, whereas magnetic or electric forces may be either attraction or repulsion. Then, too, gravitation acts between any two objects, while magnetism is exhibited by only a few special substances. Moreover, electric and magnetic forces can be screened off by suitable materials, gravitation cannot. You see, Nature remains complex enough to be interesting.

The quantity of electricity that you put on an insulated metal ball is measured by bringing the ball up to a certain distance from a standard charge and seeing how strong a force is exerted between them. The practical unit of electric quantity is called a **coulomb** after the French experimenter of that name. About this amount of electricity passes through an electric bulb every two seconds, yet in terms of electrons, a coulomb amounts to slightly over six billion billion of these tiny units.

The quantity of electricity involved in the experiments you have already performed is in every case very small; but another determining factor, called the **potential** of the charge, is quite high, even for a rubbed comb. The potential of a charge is measured by how much work must be done to bring up a small charge of the same kind from a great distance,

against the repulsion existing between them. The practical electrician measures a potential in **volts**. The difference in potential between the two wires in a household electric circuit is usually 110 volts, that between the terminals of a flashlight battery usually 3 volts, while potentials of billions of volts may exist in lightning flashes. If two charges at different potentials are joined by means of a conducting wire, an electric current—a stream of electrons—flows from the body of higher potential to the lower, just as water flows from a higher to a lower level, or as heat flows from a point of higher temperature to one that is lower.

The more electricity you put on an insulated conductor, the higher its potential becomes, just as the pressure in a water tank increases as more liquid is added, or as the temperature of a piece of iron goes up as more heat is supplied to it. When the electrical potential is high enough, the charge may, as we saw, jump off in the form of sparks. The ability of a body to hold electricity is appropriately called its **electrical capacity**. In general, as you might expect, the larger the object, the greater its capacity. The capacity of a body may be increased greatly by placing a grounded conductor close to it. A “sandwich” made of two flat metal plates separated by a thin layer of mica, glass or waxed paper constitutes what is known as a **condenser**. Similar storehouses of charge are indispensable parts of radio sets, telephones, etc.

In the middle of the eighteenth century, PIETER VAN MUSSCHENBROEK of Leyden, Holland, attempted to “electrify water” in a partly-filled flask. A nail, thrust through the cork, was connected to an electric machine. The master held the flask in one hand while it was being charged and then one of his pupils removed the connecting wire; he received a jolt from which he did not recover for two days, and MUSSCHEN-

BROEK, writing about it, said, "Not for the crown of France could I be persuaded to experience such a shock." The contents of his flask evidently had much more "kick" than the best products of the distiller's art. This form of condenser later came to be known as the Leyden jar. Certainly it jarred the early experimenters.

Less painful and fully as instructive is the following experiment with a flat plate condenser of your own construction. You'll need tinfoil in the form of a number of candy or gum wrappers and a half dozen thin, flat pieces of glass, such as old photographic plates. Make a pile of alternate glass plates and tinfoil rectangles and have the latter about half an inch smaller than the glass plates on all sides. In making the stack, let a narrow tab of foil project out from each rectangle beyond the edge of the plates,—one on one side, the next on the opposite side. Begin the pile with a foil rectangle and end it with a glass plate. Now twist together all the tabs on one side and do the same on the other side. Join one tab to two lengths of wire, one of which is connected to a water faucet, the other having one of its ends twisted around the end of a stick of sealing wax or a glass rod. Be certain that all contacts are clean by scraping any metal surface that seems dull or greasy. With the stick resting on a sheet of dry paper, electrify the other tab and the foil sheets attached to it by touching the tab repeatedly with the charged electrophorus plate. Then lift the free end of the wire carefully by means of its insulating handle and bring it near the tab that was charged. The resulting spark will be spectacular.

16

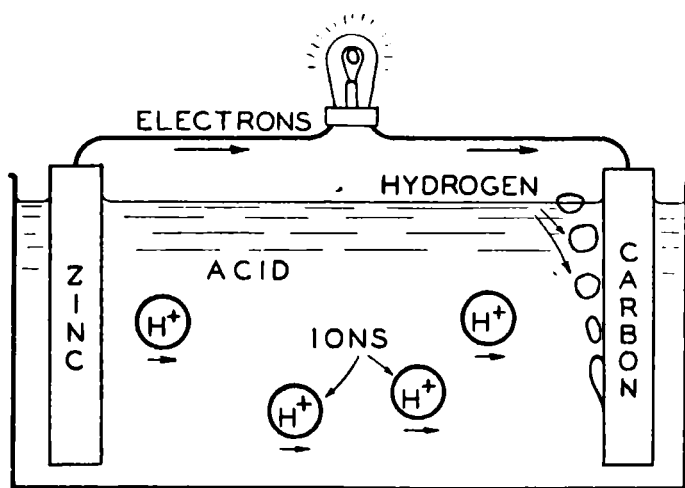
ELECTRICITY AT WORK

THE many wonderful technical applications of electricity—electric power and lighting, the telegraph, telephone, radio, television—all depend on electricity in motion: electrons swarming through spaces between the atoms of a wire or winging their lone way across the void inside a vacuum tube. For that's what an electric current is: electrons, or sometimes ions, in motion. As long as the world knew electricity only as a peculiar effect resident on rubbed amber and in the clouds, it remained a mere curiosity. Like a Missouri mule, electricity is a useful source of power only when in motion.

At about the time France was preparing for her bloody revolution, an Italian physician named GALVANI was dissecting a frog in his laboratory at Bologna. To his surprise he found that the frog's leg twitched vigorously whenever it was allowed to touch two metals, such as copper and iron, in contact. GALVANI came to the mistaken conclusion that the contractions were due to some sort of "animal electricity," and a great series of arguments began to rage between prominent scientists of that day. The true explanation was finally given by ALESSANDRO VOLTA of the University of Padua, who believed that the twitching of a frog muscle was caused by an electric charge from the metals. Deciding that electricity could be produced from the metals alone, without the aid of the frog's leg, he built what was later called a voltaic pile—a stack of alternate zinc and copper discs separated by discs of leather or paper soaked in salt water or lye. Thus he produced the

first **electric battery**, making available for the first time a continuous source of electricity,—one much more reliable, more readily controlled than rubbed rods and other sources of static electricity.

The **dry cells** that operate flashlights, portable radios, etc., use zinc and carbon as the two elements, and a moist chemical paste in place of the salt solution. When the cell is used, both zinc and carbon dissolve chemically in the paste. The zinc wastes away more readily, and the result is a difference of potential between the two elements. It's this potential difference that drives the current around the circuit. Inside the



What goes on in a battery

battery, the electricity is transported bit by bit in the form of positive-charged hydrogen ions that wander across from the zinc to the carbon. In the outer circuit, the current consists of electrons moving also from zinc to carbon.

The stream of negative electrons going from zinc to carbon is equivalent to a positive current from carbon to zinc. That's not as hard to understand as it may seem. Imagine several coins laid in a row, just touching each other, with say the

second one from the right hand end removed. The coins represent electrons, the unoccupied space represents a positive charge. Now, if the coin occupying the place just to the left of the vacant space is moved over into this space, and if this process is repeated, the coins always go to the right, while the empty *space* moves across the row toward the left. The act of moving coins (electrons) one way is the same as moving spaces (positive charges) in the opposite direction. Electricians take the conventional direction of the current in the outer circuit to be that of a positive current—carbon to zinc—although the electrons, which are negative, really go the other way 'round.

Have you ever “tasted electricity”? Hold a clean penny and dime in contact at one edge and insert the tip of your tongue between the flat surfaces of the coins. The bitter-sour sensation is due to the **ions** formed in the saliva by this simple voltaic cell.

While metals carry currents by means of electrons, most liquids and gases depend on ions to transport electricity. When a substance like sugar dissolves in water, the molecules remain intact and electrically neutral; they are unable to carry a current. But when salt molecules or baking soda molecules are put into water, they immediately break up, each into a positive ion and a negative ion which can wander over to the plate of opposite charge and thus transport electricity across the solution. Water itself, by the way, has practically no ions in it, and so is a non-conductor. However, the impurities it usually contains furnish enough ions to make it a conductor. That's why it's dangerous to touch electric cords or switches with wet hands or when standing on a wet floor.

We already know that the gases of the air will carry electricity if tremendous potentials are applied, as in a flash of

lightning, but gases can be made to conduct electricity in a much milder and quieter way with voltages of only a few thousand if the gases are at low pressure. If a glass tube containing air or any other gas is pumped down until the pressure is only about $1/300$ of normal air pressure, an electric current can be made to flow through the gas by connecting a source of high voltage to two wires sealed into the ends of the tube. Then the gas glows with a soft light whose color depends on the kind of gas used. This is nothing more nor less than the neon-type tube lights that are so common now. The gas in such a tube remains quite cool; it is not burning—there's no oxygen present—but is merely glowing under the influence of the current. The process is really a complicated one in all its details, but the main fact is that ions formed in the gas, together with the electrons split off from atoms, carry the current across the tube. In the process, energy is delivered to the remaining atoms of the gas, and they give it out again in the form of light. Tube lamps represent one of man's closest approaches to the ideal "cold light" of the firefly—light without wasteful heat.

EDISON's perfection of the incandescent filament lamp in 1879 soon transformed the dim world of candles, gas lights and kerosene lamps into a place of brilliantly lighted cities and homes. An incandescent lamp illustrates the fact that when an electric current passes through a conductor, it produces heat—so much in this instance that the filament becomes white hot and gives off light, too. The struggle of the electrons to get through the network of atoms inside the filament converts electrical energy into heat. We say the filament has a high **electrical resistance**. It was the German experimenter GEORGE SIMON OHM who found the simple rule used by every electrician today, known as Ohm's law: The current

that flows through a conductor is proportional to the potential difference between its ends. In practice, the current is given in **amperes**—an ampere being the flow of one coulomb of charge (page 149) each second, just as you'd specify the current of water in a pipe as so many gallons per second flowing past a given point. And Ohm's law says that the current that flows in a wire (measured in amperes) is equal to the potential difference between the ends of the wire (measured in volts) divided by the resistance of the wire (measured in ohms).

A moderate-sized filament lamp in your home carries a current of about 0.5 ampere, and the voltage of the line is usually 110, so the resistance of the hot lamp filament is 110 divided by 0.5, or 220 ohms. In similar fashion, you can figure out how much current flows through an electric toaster whose resistance is 550 ohms when it is used on a 110-volt line. Electric current, then, is like rate of flow in a water system; electric potential (voltage) is like water pressure—the agency that causes the flow; electrical resistance is like the friction water encounters in flowing through a pipe or canal.

You will probably be more interested in figuring the cost of operating the electric appliances in your home or office. Here's how to go about it: What you pay for when you write out a check covering the monthly electric bill is the total amount of electrical *energy* the company has delivered to you in that period. The **power** consumed by an appliance—the rate at which it uses electrical energy—is figured by multiplying the current by the voltage. The lamp talked about above has a power rating, then, of 110×0.5 or 55 **watts**; the toaster, 110×5 or 550 watts. A larger unit of power, the **kilowatt**, is 1000 watts, and amounts to about one and a third horsepower. Your toaster, then, draws energy from the wires at the



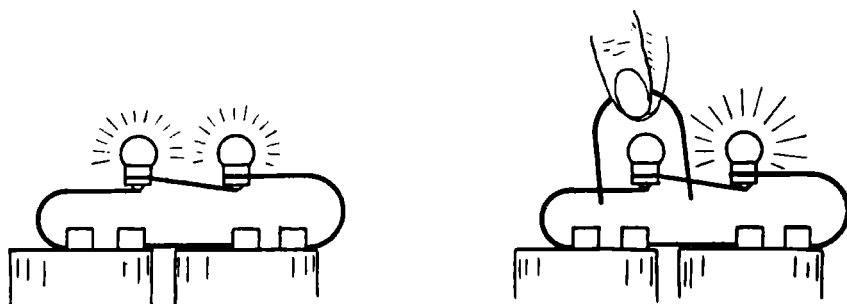
Underwood & Underwood

Boulder Dam: the power of nearly two million horses

rate of 0.55 kilowatt, or almost three-quarters of a horse-power. If the company charges for energy at the rate of 10 cents per kilowatt-hour, it costs 10×0.55 or 5.5 cents to run the toaster an hour. The meter in your cellar measures directly the energy consumed in kilowatt-hours.

After this excursion into the mathematics of public utilities, you'll probably be glad to go back to experimenting. If you have available two flashlight lamps, two dry cells and some wire, a rough check of Ohm's law can be made easily. Hook up the cells and lamps **in series**—that is, connect the

central (positive) pole of one cell to the outer (negative) terminal of the other, then complete the circuit through the lamps so that the current flows through one after another, as shown in the diagram. The lamps will glow dimly. **Short circuit** one lamp by shunting a clean piece of wire across the wires leading to it. Most of the current now goes through the



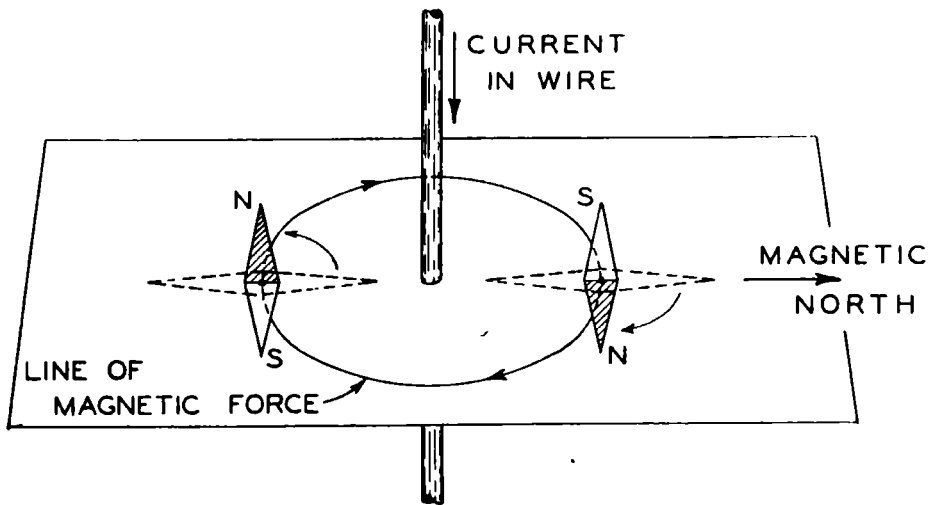
Short-circuiting one lamp makes the other brighter

“short,” which has less resistance than the lamp filament, and as a result the other lamp glows more brightly: Less total resistance, more current. Put aside the shunt and now remove one cell from the circuit. The lamps are now still dimmer, or may even be entirely dark: Less voltage, less current. Both of these findings are contained in the statement of Ohm’s law made above.

Now to an experiment on power. What becomes of the electrical energy continually going into a lighted lamp? It reappears, of course, in the form of light and heat. We can catch the emitted energy and measure it by immersing the lighted bulb almost to its socket (care!) in a can of water placed on folded newspapers. Using a thermometer and a watch, record the length of time it takes a 25 watt lamp to warm the water by 10° . Replace the 25 watt lamp by one of 60 watts, and you’ll find that in the same length of time the temperature will rise $60/25 = 24/10$ as much, or 24° . The

heat energy delivered is proportional to the wattage of the lamp. Only about one per cent of the electrical energy is converted into light energy; the rest goes into heat. The new gas-filled tube lamps with a coating of fluorescent material on the inner surface of the glass are over five times as efficient as filament lamps:

So far your occupation with electric currents revealed that they produce chemical effects and heat, but perhaps the most important technical applications of electricity depend on another effect discovered by a Danish professor of physics, HANS OERSTED, just a little over a century ago. While demonstrating the behavior of electric currents to a class, he idly brought a wire carrying a current near a compass needle. Instantly the needle swung aside. OERSTED was amazed, for up to now electricity and magnetism were considered quite distinct things. The wire was made of copper, he reasoned, so it itself couldn't attract the needle. What is more, the effect stopped as soon as



Electric current flowing in the wire turns aside the compass needle

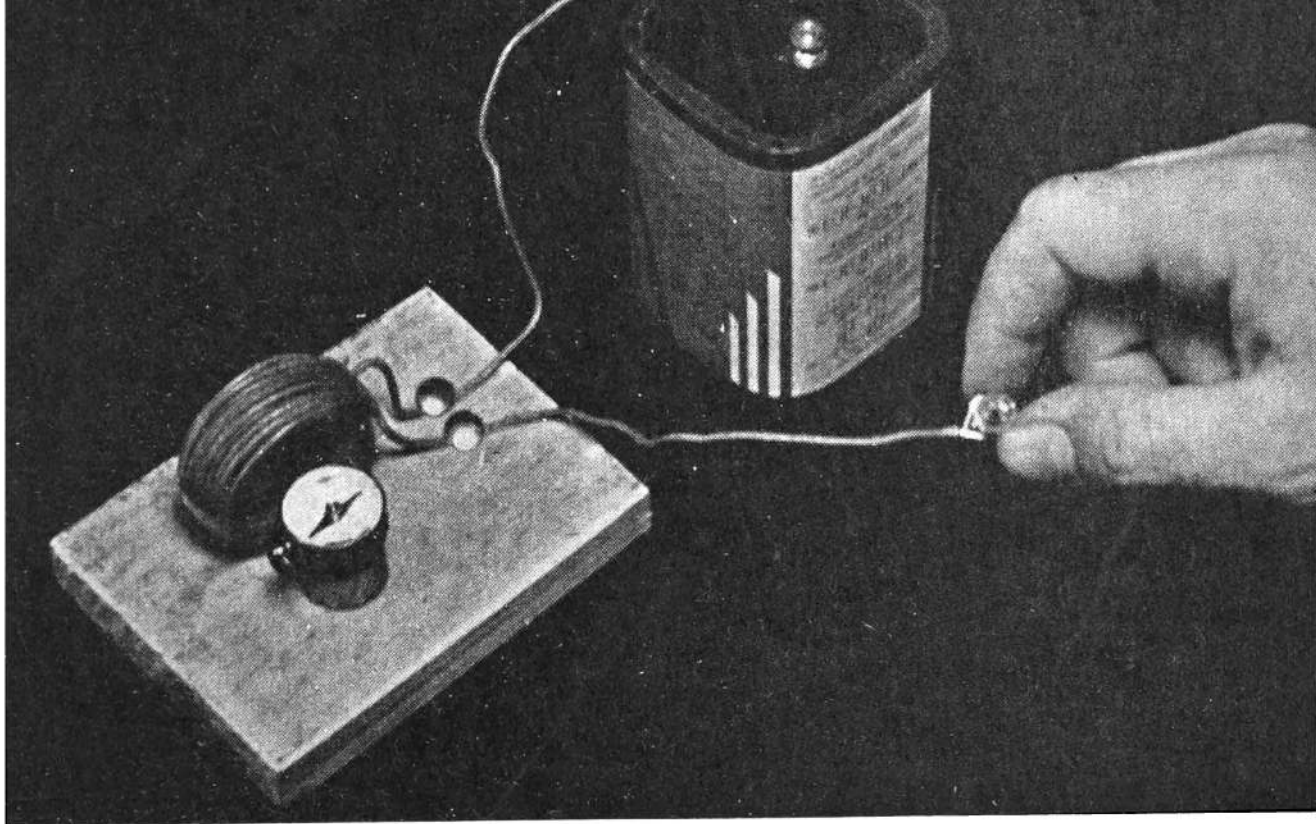
the battery was disconnected. What OERSTED found was that a straight wire carrying a current has a magnetic field in its neighborhood. The lines of force of this field have the form

of circles running around the wire. Reverse the current, and they run around the opposite way.

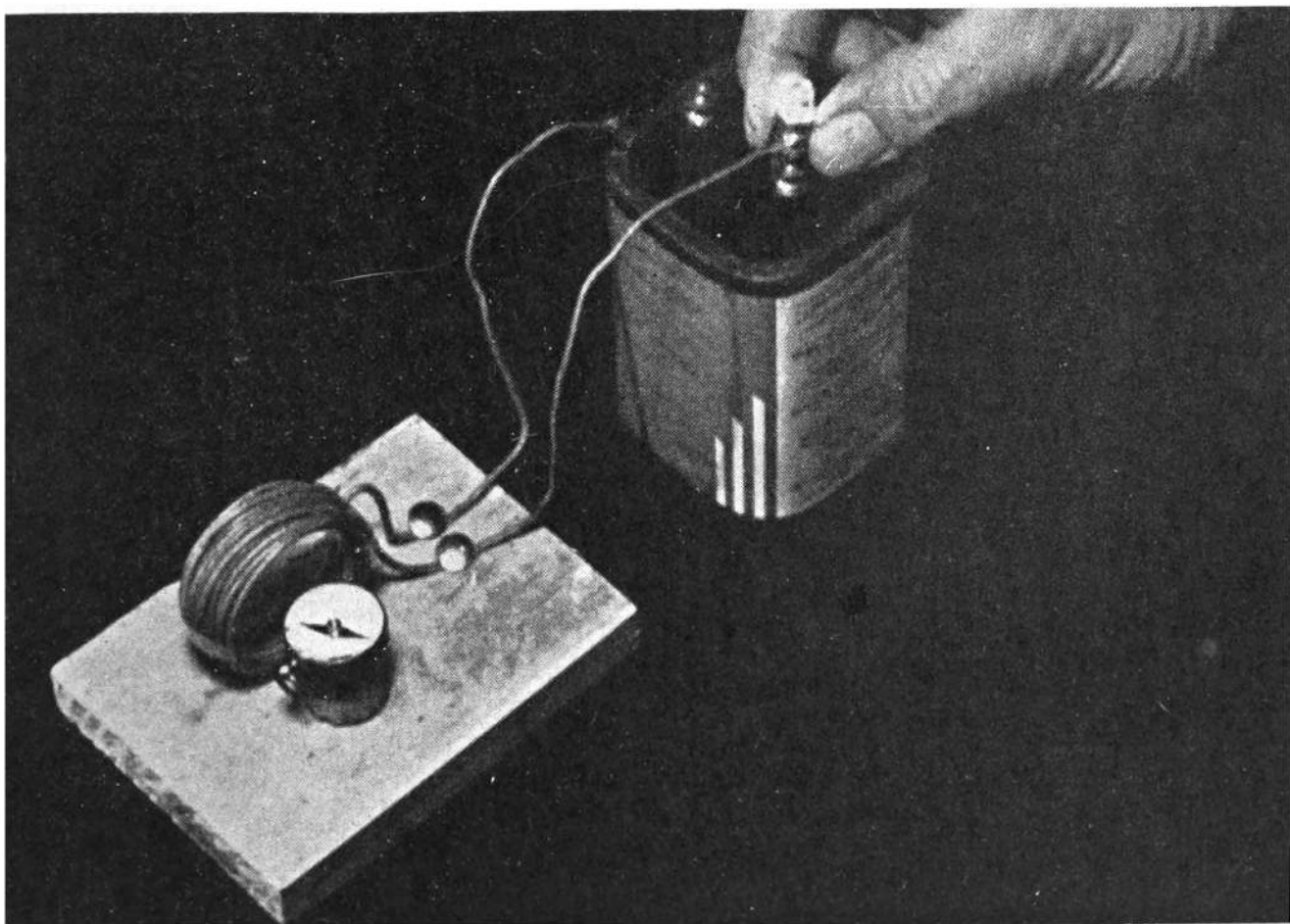
Now at last were electricity and magnetism united, and right then and there was born the basic idea of the electric motor, the telegraph and all such useful devices. It was only a few weeks after OERSTED's discovery that the great mathematical and electric genius, the Frenchman ANDRÉ MARIE AMPÈRE, found that if the wire is wound into the form of a spiral coil, the effects are much increased. It's simple to make a **galvanometer**, or current detector, using such a coil. This instrument will be useful in the experiments that follow. Wind a dozen turns of bell wire on a small glass or bottle. Slip the windings off, tape them together, and mount the coil in a vertical position on a block of wood. Place a pocket compass opposite the center of the coil and set the arrangement in a north-south direction, so that the face of the coil is parallel to the compass needle. If the coil is connected to a battery, the flow of current will be indicated by the swinging aside of the needle, the extent of the swing depending on the strength of the current. A galvanometer whose scale is marked off to read amperes directly is called an **ammeter**. Reverse the battery connections of the galvanometer and the needle swings the other way. A steel rod placed in a coil that carries a heavy current will be a permanent magnet afterward.

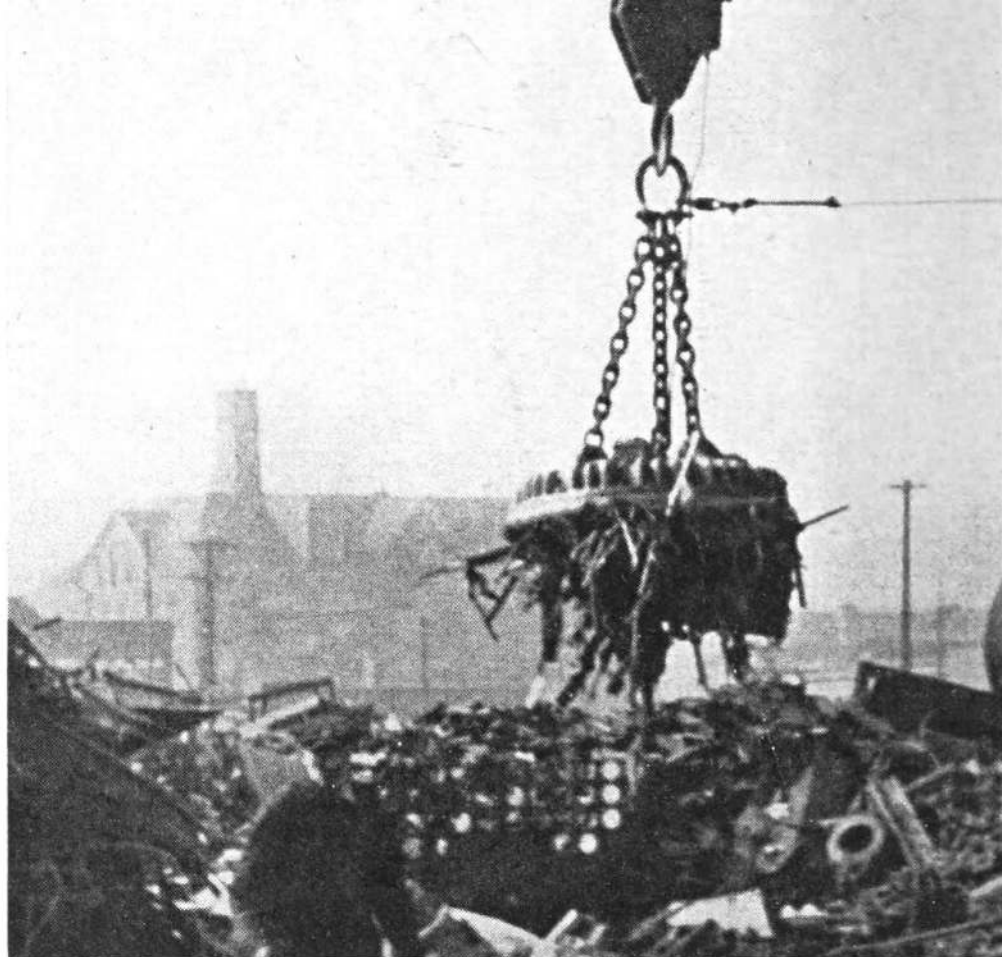
The coil itself acts in every way like a bar magnet, even to having two poles, one near each end. It's called an **electromagnet**. If such a coil is freely suspended, it swings into a north-south position when the current is turned on.

Examine an electric door bell and notice that the important feature is an electromagnet, or two such magnets, each consisting of many turns of fine wire wound on a soft iron core. When current flows in the windings, a bar of soft iron at-



The compass needle swings aside when a current flows through the coil





A magnet powerful enough to lift heavy loads

tached to the hammer is attracted, striking the gong; but as soon as the bar moves over it opens a contact that interrupts the current, the magnet becomes inactive and a spring pulls the bar back, closing the circuit again. The operation repeats many times each second.

A very serviceable battery-operated telegraph system can be made from the parts of discarded door bells.

The electric motor is probably one of the most useful of all electromagnetic machines. The rotating part, or **rotor**, consists of a set of electromagnets that are attracted and repelled by the stationary set of electromagnets. The **commutator** of the motor automatically reverses the current in the coils at the right instant to insure the rotor's turning always in one direction. You can think of the electric motor as a device for converting electrical energy into mechanical energy, or motion. A very simple but instructive little motor that runs on a

dry cell can now be purchased in ten cent stores and toy shops.

It was not long after OERSTED had discovered that an electric current produces magnetism that people began to wonder if the reverse weren't true: Can magnetism produce an electric current? An affirmative answer was given by FARADAY in 1831. The same conclusion was reached at about that time by JOSEPH HENRY, an American scientist and teacher, but FARADAY was the first to announce it.

In order to see what this effect is, wind a coil of about 20 turns of bell wire, compact enough so that the horse-shoe magnet can be slipped over it, and connect the coil by means of long wires to your simple galvanometer placed a yard or so away. Now slip the flat coil rapidly between the poles of the magnet. Observe that a current flows momentarily in the galvanometer, although no battery or other source of current is present. Withdraw the coil from between the poles of the horse-shoe magnet quickly and a momentary current flows in the opposite direction. A few trials will show that the currents flow only while the coil is *moving* with respect to the magnet. FARADAY called them **induced currents**, and the whole phenomenon goes by the high-sounding name of **electromagnetic induction**. And now the mutual relationship between electricity and magnetism is complete: A current in a wire produces a magnetic field; a magnet moved near a wire produces an electric current.

FARADAY, with his keen insight, realized that the current was caused by the wire *cutting across* the lines of force of the magnet. The faster the lines are cut, the higher the voltage of the induced current.

Without the principle of induction there would be no electric power industry today, for the electric **dynamo** or **generator** working on this principle is the only source of current

adequate to our present needs. Coils of wire on the rotor of the generator are moved past stationary electromagnets, and currents are induced in the coils as a result. The currents are then led out to the line. A dynamo, then, is a machine for converting mechanical energy into electrical energy, in which form it can be transmitted over considerable distances, then converted into heat or light or motion as required.

The same machine can be used, with minor adjustments, as either motor or dynamo: Pass current into its coils and rotation results—you have an electric motor. Spin the rotor by means of some source of mechanical power, and a current can be drawn from the windings—the machine is now a dynamo.

There is another device indispensable in the power industry,—the **transformer**. It consists merely of two coils wound upon an iron bar or ring. It has no moving parts, yet it can alter the strength and voltage of a current in almost any way desired, and with very little loss. Make a simple “air core” transformer by winding two circular coils, one of about a dozen turns and the other of only three or four turns, and place them flat together. Connect the second coil to the galvanometer, and join one wire of the first coil to one terminal of a battery. Now complete the circuit of the first coil by touching its remaining wire to the other side of the battery. Notice that in spite of the fact that the two coils of the transformer are not joined electrically, a momentary current flows in the galvanometer at the instant contact is made in the other circuit. A reverse “kick” results when this circuit is broken.

The currents, as you suspect, are produced by induction. Here’s what happens: Sending the battery current through the first coil makes it an electromagnet, and its lines of force shoot through the nearby second coil. The effect is the same

as thrusting a real magnet into the second coil, and we already know that this induces a current in it. The same thing happens when the circuit of the first coil is broken: The coil ceases at once to be a magnet, and that's the same as withdrawing a real magnet from the second coil. The result is a current in the opposite direction. If this seems complicated, remember that electricity, by its very nature, is not as accessible to experience as mechanics, where you can see and feel and handle the things talked about.

But to get to the practical angle of the subject of transformers: The main use of a transformer is to change the voltage of a current. If the second coil has, say, 10 times as many turns as the first one, the induced current in the second coil will have 10 times the voltage of the first, but will be only $1/10$ as strong. In order to have a current flowing in the second coil all the time, it is necessary to keep *changing* the strength of the primary current continually. Now a current of regularly varying strength is just what a generator without a commutator produces, because its windings sweep across opposite poles of the stationary magnet coils one after another—first an N, then an S, then an N, etc. As a result, the output current flows first in one direction, then the other—an **alternating current**.

The current in your household wiring is 60-cycle alternating current; that is, it makes 60 to-and-fro swings each second. This is so fast that the lamp filaments do not have a chance to cool down between surges, and no flicker is noticed. The use of alternating current makes it possible to employ transformers, which greatly facilitate the efficient transmission and distribution of the power. Your house current may have been generated at 10,000 volts, stepped up by a transformer to 200,000 volts, transmitted on a high-tension line to

the outskirts of your city where a transformer stepped it down to 2300 volts, and finally stepped down by a smaller transformer on a pole outside your house to the 110-volt potential at which it enters your home.

Electrical circuits constructed out of coils and condensers can be made to respond by an electrical resonance process to vibrations of around a million per second. These are the circuits used in radio sets. The incoming radio waves, which are of an electromagnetic nature, can make the circuit respond only when it is **tuned** (by turning knobs to adjust condensers) to the same frequency as the wave to be received.

The operation of the telephone, too, depends on induction. The sound waves of your voice set the soft iron diaphragm of the **transmitter** (see drawing) into vibration. The result is that the lines of force of the permanent magnet in the



Simple telephone (schematic)

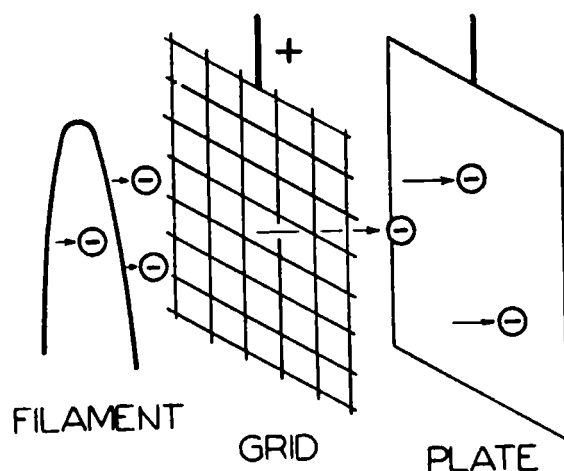
transmitter sweep back and forth across the wires of the coil wound on it. As a consequence, a feeble fluctuating current is induced in the wire, its variations being a copy of those of the sound waves. This current, flowing in the coil wound around the permanent magnet of the **receiver** at the distant station, causes corresponding variations in the strength of the magnet, the soft iron diaphragm is set in motion in the same tempo as the original sound waves, and you hear the voice of the person at the other end of the line. The introduction of alternating currents and the use of vacuum tubes makes a

modern telephone circuit much more complex, but the basic principle is the same.

Induced currents arising in the metal parts of electrical machinery are called **eddy currents**. Stick the eye end of a needle into a cork, and balance a thimble, preferably a silver one, on the needle point. Hang a horse-shoe magnet through a foot-long loop of thread so that the ends of the magnet are about a quarter of an inch directly above the top of the thimble. Twist up the thread and release the magnet, which will spin as the thread untwists. Very soon the thimble will begin to turn in the same direction; it is an **induction motor**. Silver, of course, is non-magnetic, so the effect cannot be due to direct magnetic attraction. Neither is the thimble's motion due to air currents, for it works as well when a card is inserted between thimble and magnet. The turning is caused by currents induced in the metal by the moving magnet—the eddy currents mentioned above. Each little whirl of current constitutes a magnet that reacts on the horse-shoe magnet. In transformers and other electrical devices eddy currents waste electrical energy. The losses are minimized by making the magnetic cores out of many thin strips of iron, insulated from each other, rather than using a single large piece.

In connection with his invention of the incandescent lamp, EDISON noticed that the hot filament continually gives off a swarm of electrons, but he seems to have made no use of the effect. Electrons escaping from the hot wire fly across the vacuum inside the lamp, and can be caught on a metal plate sealed into the side of the glass. If, also, a wire mesh is placed in the vessel between the filament and the metal plate, and if this mesh or grid is given a slight positive charge, it will attract the electrons, letting them shoot through the holes in the grid to land on the plate beyond. This, then, is a **radio**

tube. Small variations of potential applied to the grid control the electrons streaming to the plate, and by hooking up a number of such tubes, a weak current induced by a feeble incoming radio signal can be **amplified** and made to work a loud speaker.



It revolutionized our world: the vacuum tube (schematic)

Another way of coaxing electrons from a metal is to let light shine on a metal surface placed in a high vacuum. The liberated electrons go across the tube almost instantly and land on another plate, where they are detected. Electricity from light! Similar **photo-electric cells** can be made to operate electromagnets which in turn may actuate door-opening mechanisms, control traffic lights, turn in fire alarms, count articles passing on a belt conveyor, transmit pictures by wire, or do other wonderful things automatically. Camera enthusiasts use a special form of photo-cell as a convenient light meter. Talking motion pictures and television are other developments that depend on the versatile photo-electric cell—the magic eye of the world of electrons.

SHADOWS AND REFLECTIONS

LIGHT is the roving tale-bearer of the universe. It tells us that in the remote reaches of the cosmos, the same natural laws hold as here on earth. It brings us by far the greater amount of our knowledge of things both near and distant. Without light, this would be a dull, uninteresting place—an impossible world, in fact; for without the radiation of the sun to warm the earth, life on our planet could not exist. "All forces of the earth, all manifestations of life are modulations and variations of the same heavenly melody which proceeds from the sun," wrote the English scientist JOHN TYNDALL.

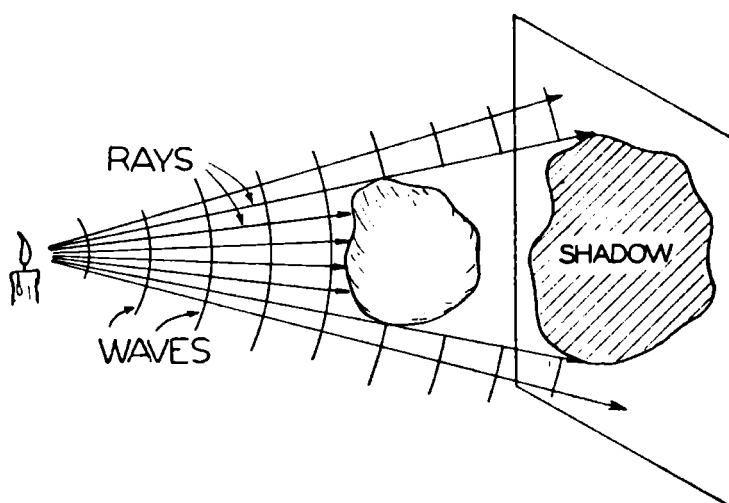
The ancients speculated about the true nature of light. They believed it to consist of small particles of some sort. The great philosopher PLATO thought these particles were emitted by the eye, and that when they struck an object, it became visible.

NEWTON believed that light corpuscles, as he called them, were given off by luminous bodies. His authority kept this theory alive for nearly a century after his time, in spite of the fact that the idea of corpuscles could not explain certain features of the behavior of light. Today we know that light consists of waves that travel through space with the incredible speed of over 186,000 miles per second, and that these waves are of an **electromagnetic** nature, like radio waves.

When you look at a steady light, you get no inkling of the fact that it consists of waves, any more than a steady sound conveys any idea of its wave-like nature. Of course, the ex-

periments that reveal the wave structure of light, like those in the study of sound, are rather indirect. Let's see first what we can find out about the behavior of light by simple observations.

The beautiful shafts of sunlight spreading fanwise from a rift in the clouds, or the beam of light coming through the cracks of a window shutter and making itself visible by means of dust or smoke particles in its path, show that light is something that ordinarily travels in straight lines. Further,



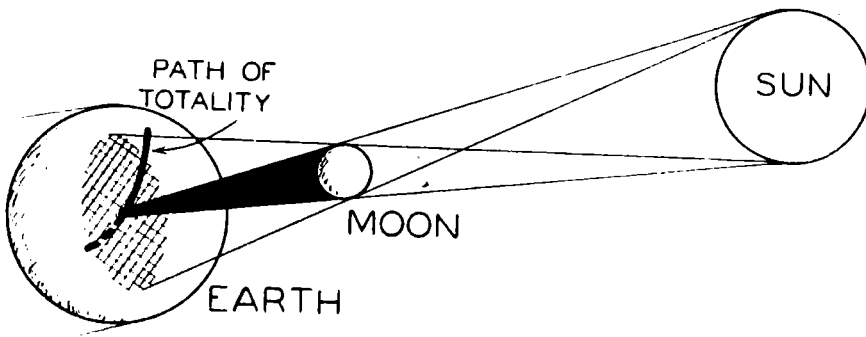
Light travels in straight lines

we know that we can't "see around a corner" without resorting to some trick. It's often convenient to draw straight lines outward from a source of light to represent the way light travels. These lines are called **rays** of light. They're no more real than lines of magnetic or electric force; the real things are the light **waves**, extending broadside to the direction of the rays.

Shadow pictures illustrate the straight-line travel of light in an entertaining way familiar to all. Use a single, small source of light such as a candle flame or unfrosted light bulb,

and cast the shadow on a white paper or cardboard for best results. Notice that the shadow can be made very large by placing the card far away and by holding the hand close to the source of light. With sunlight, the shadow is always the same size as the object that casts it, since the source is so far away that the rays come in almost exactly parallel.

If the light source is large and the object small, there will be two shadows—a central, dark one and an outer gray one. Examine the shadow cast by a ruler held close under an ordinary inside-frosted lamp and you'll find this to be true. An **eclipse of the sun** occurs when the moon comes squarely be-

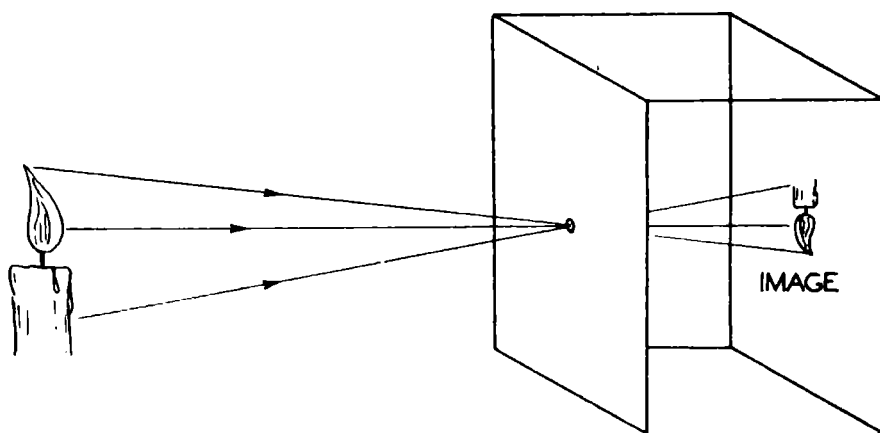


Total eclipse of the sun

tween the earth and the sun. Inside the central cone of rays no light is received from any part of the sun, while the cross-lined region gets light from part of the sun but not from all of it. As the earth rotates, the shadows sweep across it. A person in the central region experiences a **total eclipse**; one in the outer region, a **partial eclipse**.

Anybody can enjoy home movies at no expense and with no elaborate equipment. On a bright day, darken a window completely, using a heavy drape or several thicknesses of paper. Have everything light-tight except for a one-inch hole in the window covering. Now, on the opposite wall and ceil-

ing you'll see reproductions in natural colors of people and vehicles in the street outside. However, everything is upside down, and right and left are reversed! The whole room forms what is called a **pinhole camera**. No lens in this camera, but you get pictures nevertheless. It's the straight-line travel of light rays that makes this possible: Each point of a brightly lighted object outside acts as a source of light. The only rays that can enter the room are those in the narrow bundle that comes through the hole in the curtain. Each ray falls at a certain place on the wall. If the spot it comes from is bright, this place is bright; if the spot is red, this place on the wall is red; in other words, a reproduction, spot for spot, of the object. The hole in the curtain must be small in order to minimize overlapping of the conical bundles of light rays from different points on the object.

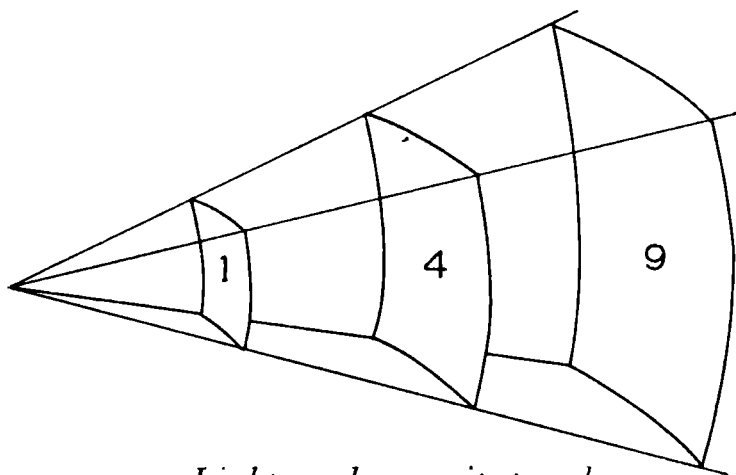


Pinhole camera

Perhaps you'd rather make a pinhole camera on a smaller scale. Cut out one end of a cardboard box, cover this end with a sheet of tissue paper, and make a hole in the center of the opposite end of the box with a needle. In a dark room, a candle flame or a lamp bulb a few feet in front of the box will be represented as a bright, inverted image on the tissue

paper screen. Notice that the greater the distance of the object, the smaller its image. Good pictures can be obtained with such a camera by replacing the tissue paper with a photographic plate or film, but because of the small amount of light entering through the pinhole, the exposure must be inconveniently long. The solution, of course, is to use a lens, as we'll see later.

Everybody knows that the illumination produced by a lamp is weaker at a greater distance from it. If we ask exactly how brightness and distance are related, we come across that familiar law we met on several previous occasions: Double the distance and the illumination is quartered; treble the distance



Light weakens as it spreads

and it is reduced to $1/9$ its former value, etc. You can easily see why this is true by looking at the diagram, showing light spreading in straight lines from a small source. The waves are expanding spheres; at twice the distance, a given "slice" of the wave has increased its surface 4 times. The same amount of light energy spreads over 4 times the surface, so its brightness is only $1/4$ what it was before.

The actual brilliance of a lamp or other source of light is measured in **candle power**—how many times more illumina-

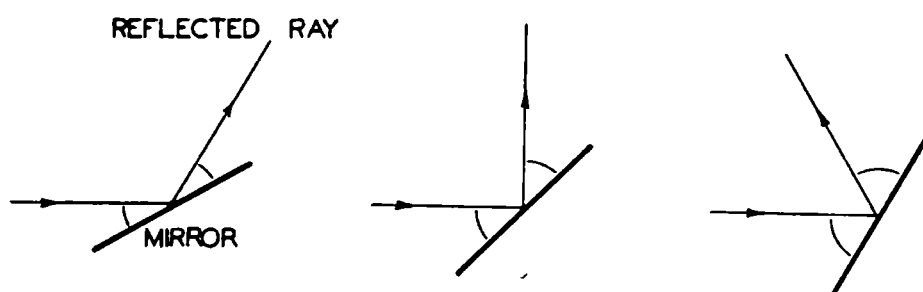
tion the lamp produces at a given distance than a standard candle. It doesn't take any complicated apparatus to measure the candle power of an electric lamp. COUNT RUMFORD's method requires only a vertical rod or slat and a cardboard screen. Prop up a ruler between books so that it is vertical and has its flat side parallel to a light-colored wall or screen about a foot beyond. Have no other light in the room except a candle and, say, a 25-watt lamp. Place the candle about two feet from the ruler. Move the lamp about until it casts a shadow that appears to have the same blackness. Then measure the exact distance of each source from the shadow cast by the *other*. You'll find that the lamp will have to be about 5 times as far away as the candle. The conclusion is that the lamp has a candle power of 5×5 or 25.

The great German chemist ROBERT BUNSEN devised another form of **photometer**, or light measurer. Make a grease spot in the center of a piece of writing paper by letting a drop of melted candle wax fall on it, scratching the wax off after it has hardened. Set the paper up vertically on the table, holding it in place with books, and place a lighted candle a foot or so in front of it. Place four other lighted candles close together on a dish and, with the room otherwise dark, place this set of four on the opposite side of the paper at such a distance that the grease spot appears least visible; that is, neither darker nor lighter than the surrounding paper when viewed from either side. You will find that the quartet of candles must be placed just twice as far from the paper as the single one, while a group of 9 candles will have to be put 3 times as far away. The reason, as you already know, is that the illumination produced by a single candle at 3 times the distance is $1/9$ of its former value, so that 9 candles must be used if the illumination is to be the same as before.

A one candle-power light source placed one foot away from a surface is said to give that surface an illumination of one **foot-candle**. For ordinary reading, at least 5 foot-candles is desirable. This would be furnished, for example, by a 50 candle-power lamp placed a trifle over 3 feet away from your book, and illuminating the page directly.

Most of the things around us do not give off light of their own; we see them by light that they **reflect**, or throw back to the eye. Materials like carpet, unglazed paper, felt, or unpainted wood reflect light rays in many different directions, because each little portion of a rough surface is turned a different way. Smooth surfaces like a polished table-top, a knife blade, or a mirror reflect all the rays in the same direction.

Light is found to rebound from a flat surface in much the same way as a rubber ball: Throw it to the floor at any angle, and it bounces off at the same angle. An easy way to verify this law of reflection for light is to place a lighted candle on

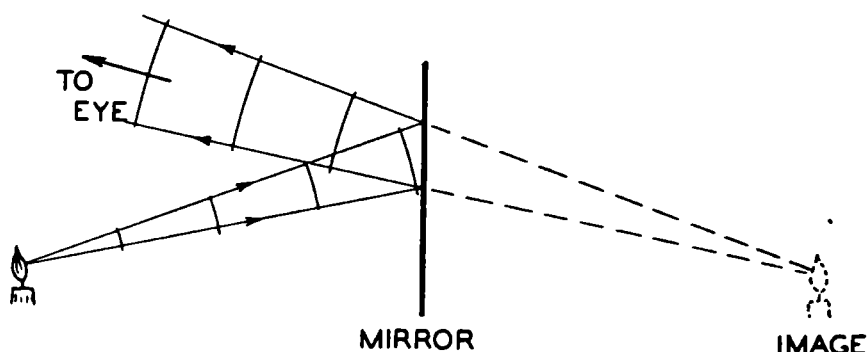


Light reflected from an inclined mirror

a table in a darkened room and, a few feet to one side, a table knife held with its blade horizontal. A spot of light will be reflected onto the walls or ceiling, its position changing as you rotate the knife. Holding the blade inclined at an angle of 45 degrees to the incoming rays from the candle, the reflected beam will be thrown straight upward; holding it at

right angles to the rays throws the light straight back upon itself, and so on. Always, the angle between the incoming ray and the reflecting surface is the same as that between the reflected ray and the surface.

It is commonly said that we look *into* a mirror to see our image there. The light, naturally, does not penetrate behind the mirror; but the rays, after reflection, seem to come from a



Light from the object appears to come from the image behind the mirror.

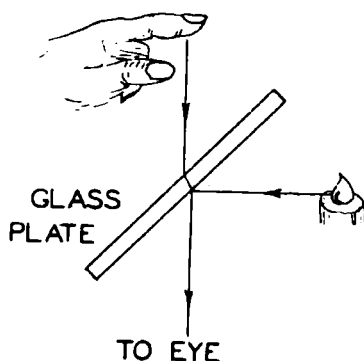
place which is exactly as far behind the mirror as the original object is in front of it (see diagram). When taking a picture of your reflection in a mirror, the camera must be focused for twice the distance between you and the mirror.

The reflection of light may be imitated by the ripple tank (page 89), since in this respect light waves behave exactly like water waves and sound waves. Let one of the straight sides of the vessel represent the mirror. Start a wave from the “source of light” by letting fall a single drop of water near one side of the vessel. Circular ripples spread out from this point and are reflected from the “mirror” as circles turned the other way—circles that have their center as far back of the reflecting surface as the source is in front of it. This is shown in the photograph on page 178.

As you know, even a piece of clear, transparent glass acts like a mirror. This is especially noticeable when riding in a train at night; you see yourself and the other passengers plainly reflected in the windows. Ordinary mirrors are silvered to increase the reflecting power and at the same time keep out confusing light coming from behind.

An entertaining illusion illustrates the position of the image formed by a mirror:

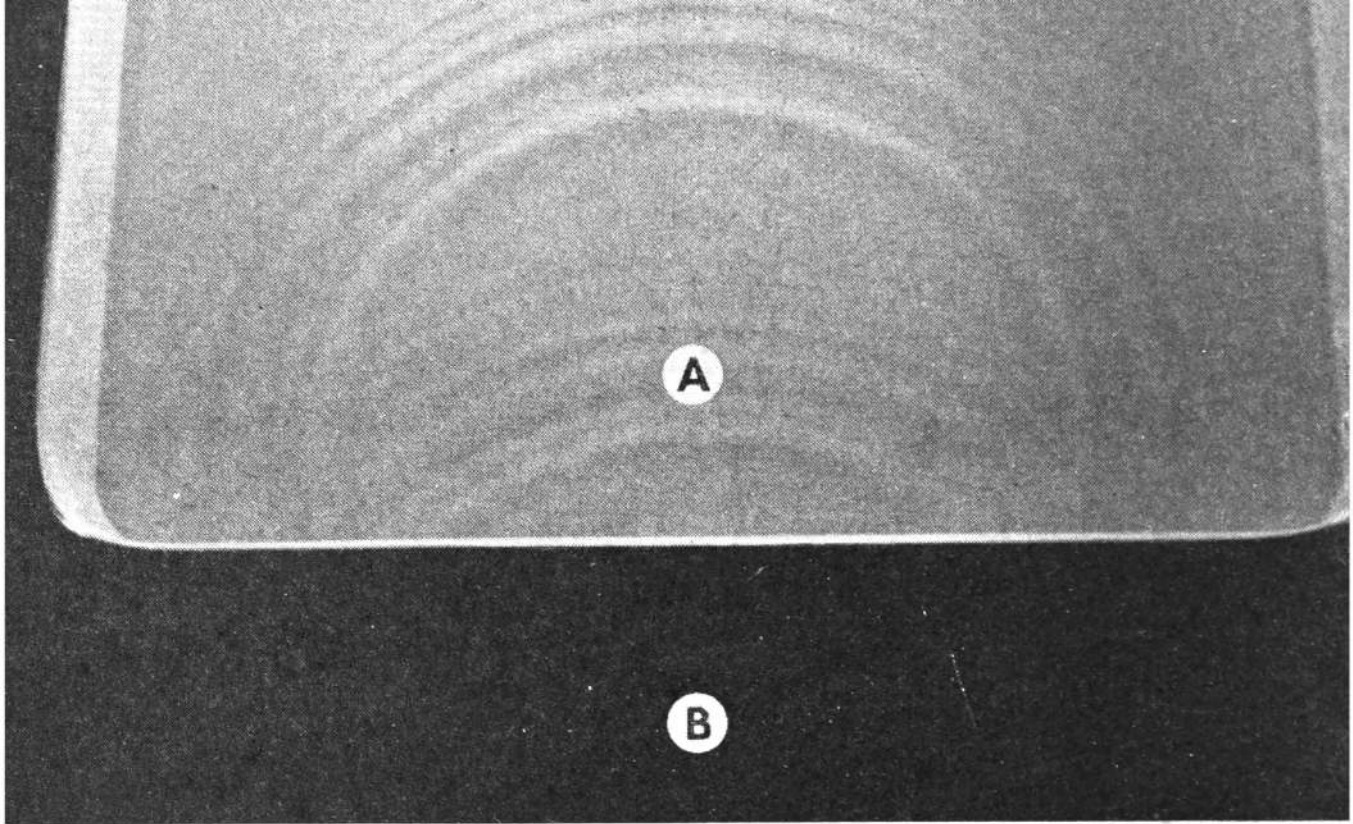
Place a lighted candle a foot or so in front of a large, flat piece of window glass propped up vertically with books. At the same distance directly behind the glass plate put a tumbler of water. Looked at from the front, the candle will appear to be burning under water, because the tumbler occupies the



Finger-in-flame illusion (top view)

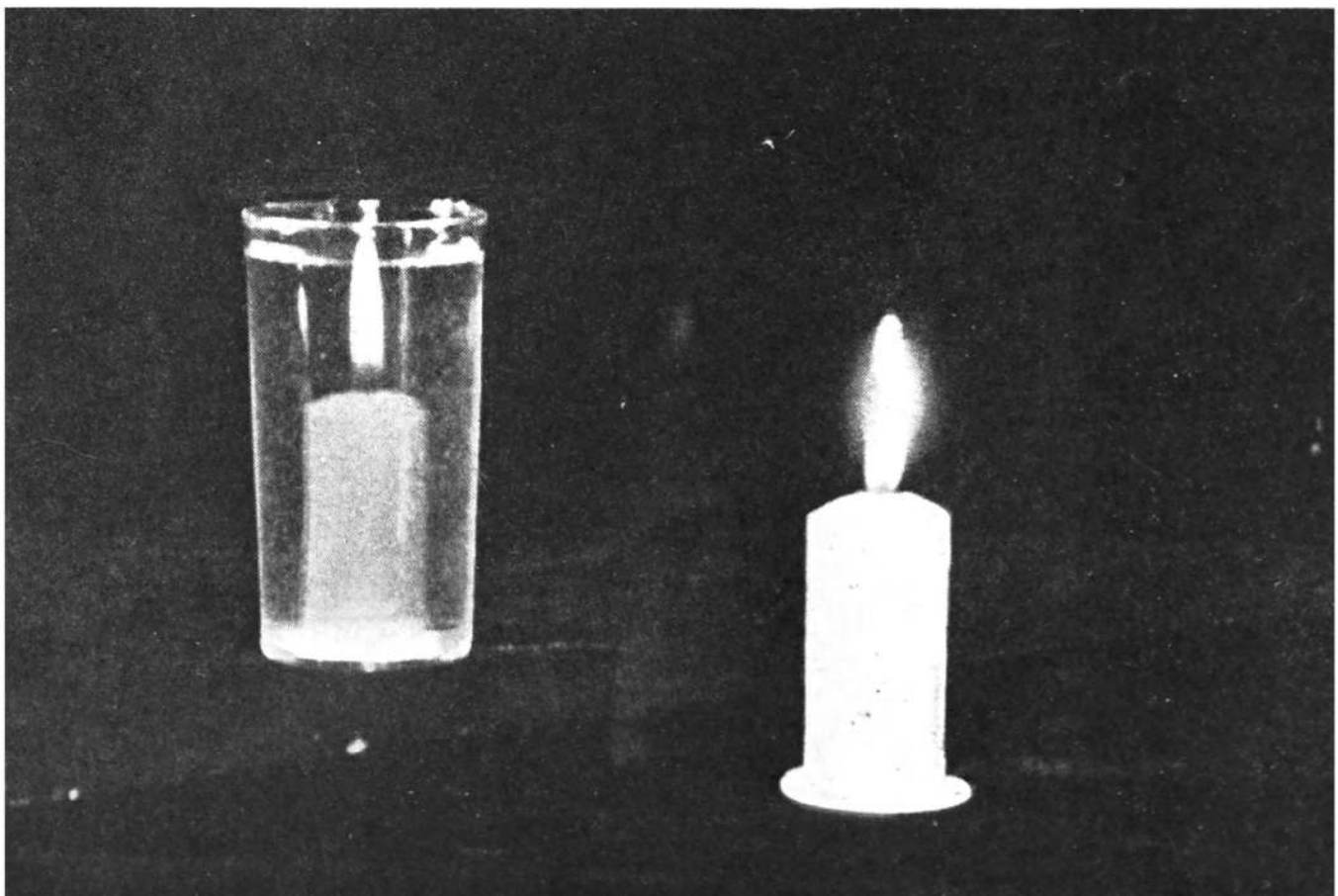
same position as the candle's image. With this arrangement, shown in top view in the diagram, you can demonstrate to spectators in an adjoining room your wonderful indifference to fire. Illuminate the hand with a desk lamp or flashlight. Stage ghosts and similar illusions are produced in the same way;—"it's all done with mirrors."

An interesting result of the fact that both the front and back surfaces of a mirror reflect light is shown by holding a pocket mirror or a thick piece of flat glass straight out from

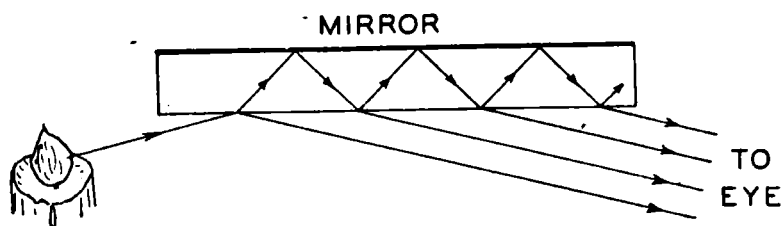


Waves originating at A appear to come from B after reflection

The candle, reflected from the glass plate, appears to be burning under water



your face, just to one side of your nose, and looking with one eye at a candle flame located almost directly ahead, so that its rays come in at a very small angle to the mirror. You will



Multiple images from a thick mirror

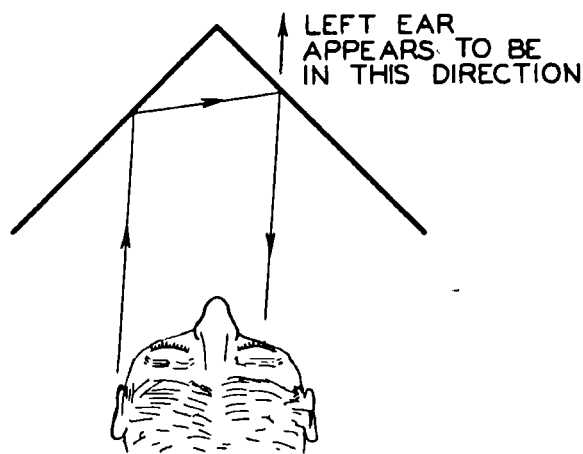
then see not only one image of the flame, but a large number, each fainter than the former. These are produced by back and forth reflection of light inside the glass, as the diagram indicates. Try the experiment in a dark room.

Even better is the experiment of setting a candle an inch in front of a vertical mirror and then placing a clear piece of glass the same distance in front of the candle and parallel to the mirror. Looking through the glass plate you see not only the candle itself, but an almost endless row of images that loses itself in the distance. These images are formed by rays reflected back and forth between plate and mirror, one, two, three . . . times. You may have seen advertising devices in store windows that use this idea. Turning the glass slightly slantwise changes the straight row to an interesting curve.

Fix two small mirrors together along one edge with adhesive tape, silvered sides facing each other like the covers of a book. Stand this arrangement on a table and place an object like a pencil or a candle between the mirrors. A multiplicity of images arranged around a circle will be seen by looking into the pair of mirrors in various directions. The number of images equals the number of times the angle between the mirrors is included in a full circle (360 degrees). For example,

if the angle between the two is 45 degrees, you will see altogether 8 images in the pair of mirrors.

The hinged mirror arrangement just used would have delighted the poet Robert Burns, who pined for a way of showing us as we really are. When you look into an ordinary mirror, you do not see yourself as you appear to others, be-



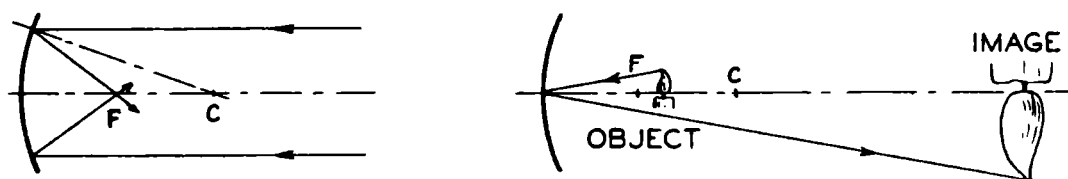
The candid mirror

cause a mirror reverses right and left—your image has the two sides interchanged. But you can make a “candid” looking-glass by using the hinged mirror pair of the last experiment. Simply open it out until the two mirrors are exactly at right angles and look into it from the front. The person you see will look familiar, yet a trifle strange. Yes, it’s you, but with your right side to the left, left side to the right—that is, exactly as you appear to someone else. See what happens when you wink your right eye, or touch a finger to your right ear. By consulting the diagram, you’ll understand how this effect is produced by the reflection of each light ray from *both* mirrors before it reaches your eye.

There are mirrors and mirrors. Forty or more miles above the earth’s surface is a layer of ions, the **ionosphere**, that re-

flects radio waves back to earth in much the same way that a mirror reflects light. Radio transmission over long distances would not be possible without this reflection, for otherwise the waves would escape into outer space instead of following the curvature of the earth.

The ionosphere is not a flat mirror, like the ones you have been working with, but a curved reflector. Such curved mirrors are in many respects more interesting than flat ones, so let's have a look at their behavior. First, obtain a hollow or **concave** mirror in the form of a shaving mirror that can be



Focusing and image formation by a concave mirror

obtained very cheaply in a drug or notion store. You know from experience that when close up to such a mirror you see an enlarged image of yourself, but perhaps you've never noticed that under slightly different conditions, this mirror can be made to project an image onto a screen. Face the shaving mirror toward the sun, and the rays will be collected and brought to a focus at a point two or three feet from the middle of the mirror, which you can show by moving a small card back and forth until you find a bright point, a tiny image of the sun. A match-head held at this point will ignite. In any case, the distance of the **focal point** from the mirror is just half the distance from the mirror to the center of the sphere of which it is a part. Measure the distance from the mirror to the focal point. This is called the **focal length** of the mirror.

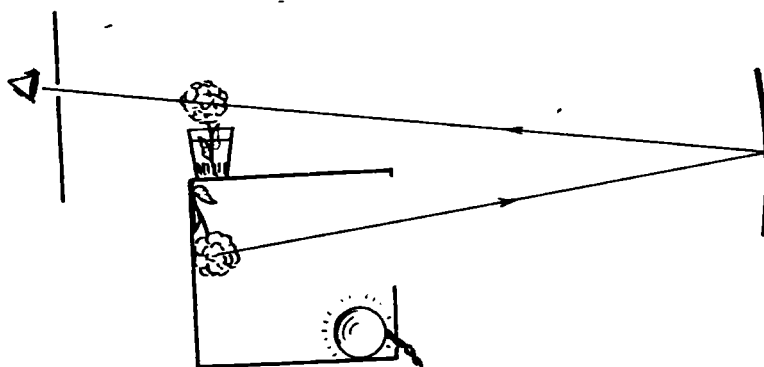
What happens when the reverse arrangement is set up—that is, when you put a source of light at the focus of a con-

cave mirror? In this instance, you have nothing but a searchlight or auto headlight: Rays from the source hit the mirror and are thrown forward in a concentrated beam. Try it by placing a candle or, better, a small flashlight bulb at the focus and throwing a circle of light on the opposite wall. If you put the candle a little beyond the focal point, you'll find a large, inverted image of it projected on the opposite wall, as shown in the second drawing in the adjoining figure. This image may be several feet high. Move the candle back and forth until the image is sharp. Note that in addition to being inverted, the image has right and left sides interchanged. Test this by blowing the flame to one side and noting that the image moves to the other side. If you take the trouble to measure the heights of candle flame and image, you'll find that the magnification is equal to the distance from mirror to wall divided by the distance from candle to mirror. Thus a 1 inch candle flame placed 4 feet from the mirror will have a 3 inch image on a wall 12 feet away.

A pleasing illusion which may be called "The Phantom Flower" can be set up with the use of a shaving mirror. The arrangement is shown in the figure. A rose, pinned upside down in a box and illuminated strongly by an electric bulb, appears to be upright in a glass of water standing on top of the box. Place the mirror at a distance of about twice its focal length from the flower, and tilt or move it until the desired illusion is obtained. Have the observers look through a peep hole cut in a cardboard, and while they are looking at the image of the rose, move your hand about over the glass to show that there is really no flower there.

A spherical concave mirror like a shaving mirror does not bring light to a perfect focus—that is, all the rays from an object do not cross at precisely the same point. You can see

this very nicely by setting a nearly-filled cup of milk in the light from a lamp or in direct sunlight so that the light comes onto the liquid surface from one side. The moon-shaped patch of light seen at the edge of the glass that faces the light



The phantom flower

is caused by the crossing of innumerable rays reflected from the rounded surface. The same effect can be observed with light reflected from the inner surface of a finger ring or can cover.

In order to make the reflected rays come to a single point, the hollow surface must be given a slightly different curvature; instead of being circular it must be a curve called a **parabola**—the same kind of curve that a projectile follows in its flight through space. Such parabolic mirrors are used in good quality searchlights and also as the mirrors in reflecting-type telescopes used in astronomy. The mirror brings light to a focus, and the resulting image is examined with a magnifying eye-piece consisting of lenses. Such mirrors must be accurately shaped to within a millionth of an inch. The newest and largest reflecting telescope, the one atop Mount Palomar in California, has a mirror 200 inches across. It gathers in a million times as much light as the unaided human eye.

A bright steel ball, a round silvered Christmas tree orna-

ment, the rear-view mirror on a car are **convex mirrors**. Unlike concave mirrors, these are not able to bring light to a real focus or to cast an image on a screen. On the contrary, they cause light rays to diverge, as you can see from the dia-

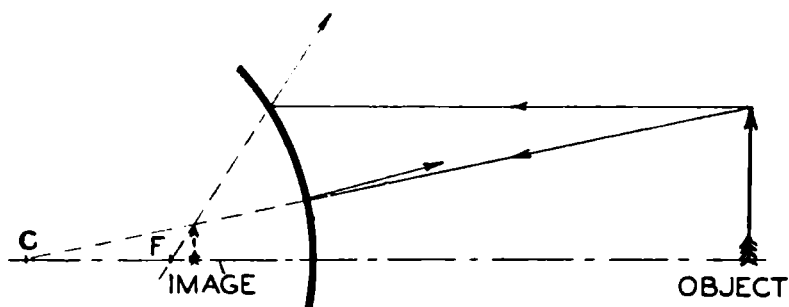


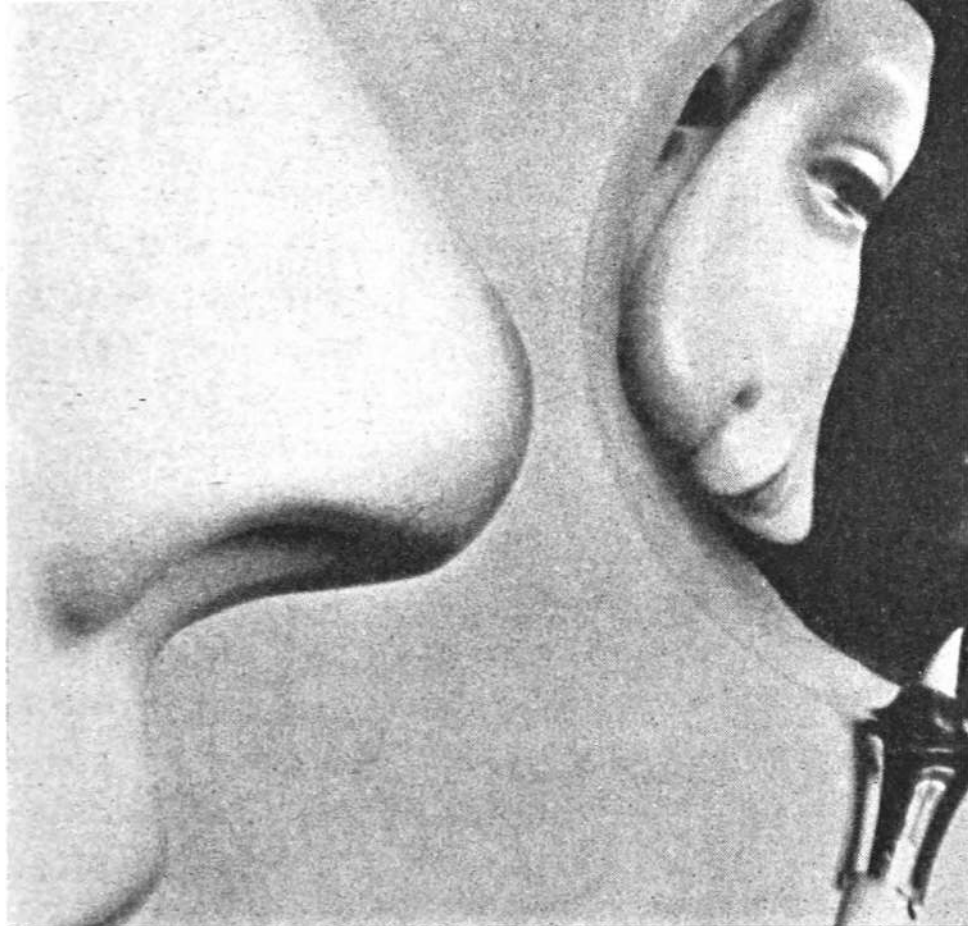
Image formation by convex mirror

gram. An image that can be thrown on a screen is appropriately called a **real image**; one for which this is not possible is called a **virtual image**. Flat or convex mirrors form virtual images. The image is behind the mirror; the light rays merely *seem* to come from it. Such an image can be viewed by the eye, but cannot be projected on a screen without using additional mirrors or lenses.

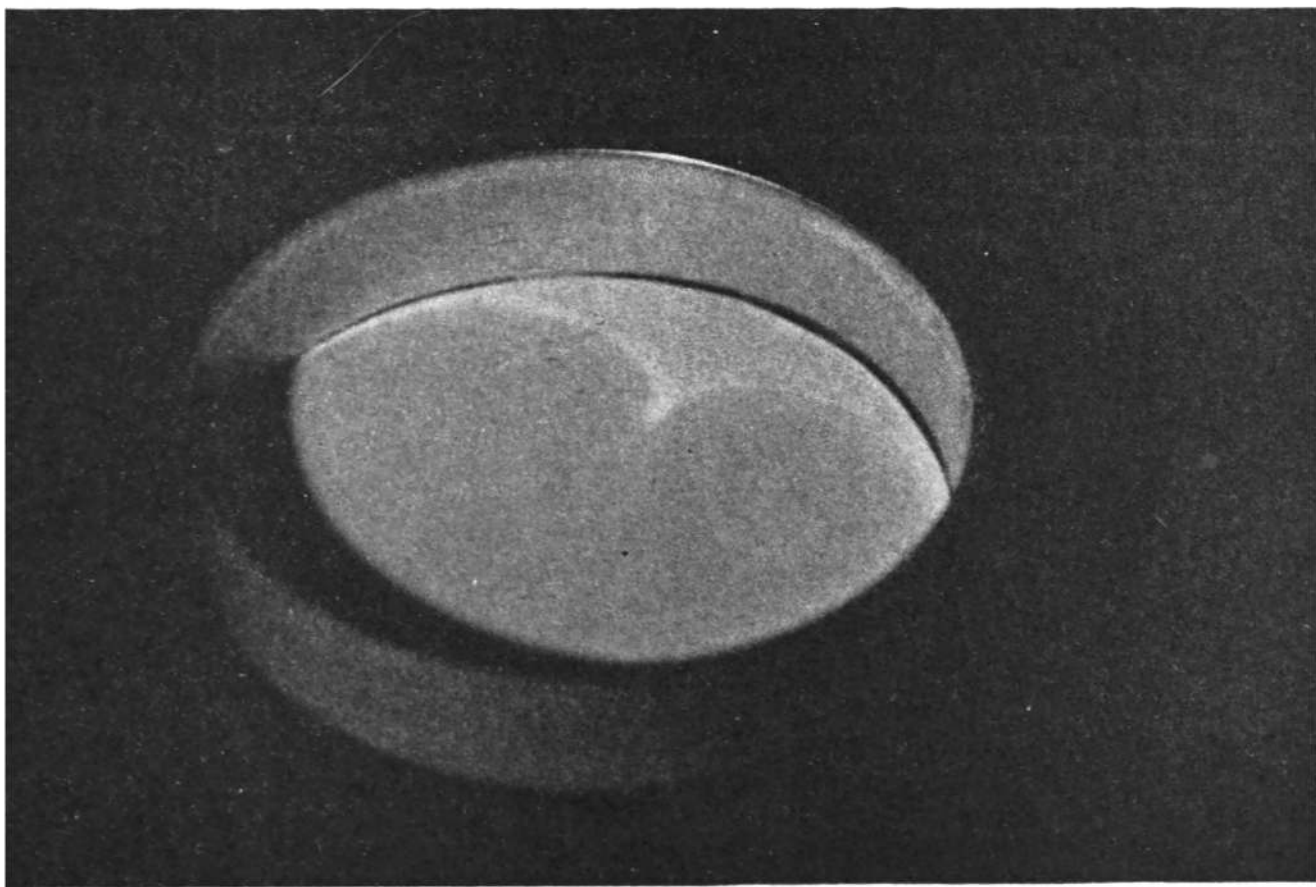
An uncolored, silvered ball used for Christmas tree decoration serves as a good convex mirror for the following experiments. First, look at the reflection in such a ball, and notice that nearly the entire room is mirrored. Now concentrate on your own reflection. You will be amused—perhaps startled—at the distortion of your features. The nearer parts of your face are enlarged much out of proportion to the rest. Notice how big your nose appears to be. The effect can be increased—if you enjoy that sort of thing—by placing a magnifying lens (reading glass) before one eye. This enables you to bring the ball close to the eye, yet see the image distinctly.

The distorting mirrors seen in amusement parks are curved

*A silvered
ball is an
unflattering
mirror*



Crescent-shaped patch of light reflected from a concave surface



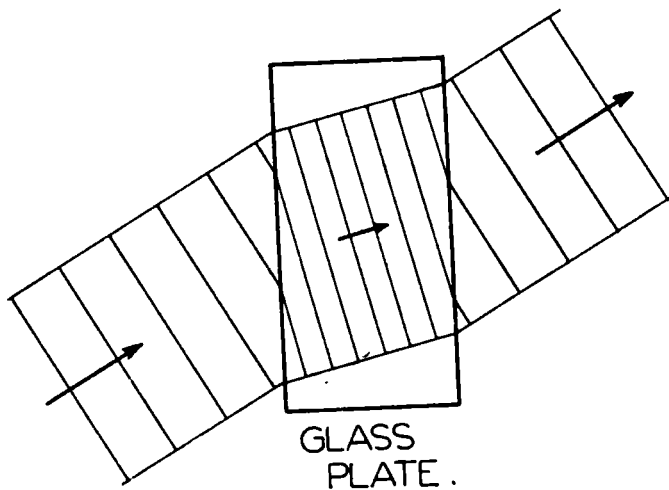
mirrors having various curvatures horizontally and vertically. You can get the same effect by looking at your reflection in the back of a highly polished silver spoon. Holding the handle horizontal makes the handsomest person look like a hippo; holding it up and down makes him look like a beanpole. Do the same thing, using the hollow side of the spoon and you get similar images, but upside down and reversed side to side.

You'll find it interesting to study the waves reflected from curved surfaces, using the ripple tank. Stand round saucepans or curved pieces of tin in the tank to serve as curved mirrors and send waves toward these reflectors by means of a knife blade. Observe the change in curvature of the waves after reflection. In this way you can duplicate many of the above situations concerning the reflection of light waves from curved mirrors.

18

LIGHT ERRANT

PLACE a spoon or a stick slantwise in a glass of water. Sighting nearly along the object, observe that the part under water appears to bend sharply upward at the water line. Look at a pencil through a thick piece of flat glass held at an angle to the line of sight and notice that the part of the pencil behind the glass seems to be staggered to one side. The basic reason for these and many similar effects is that light travels more slowly in water and in glass than it does in air. As a result, the part of a wave that strikes the water or glass first is slowed up while the rest of the wave continues at its former speed.



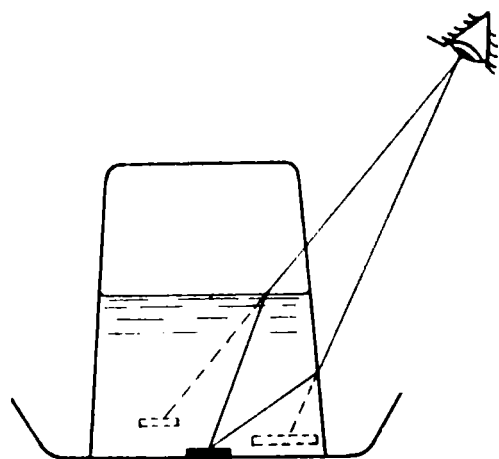
Light bends on entering and leaving a glass plate

The effect is to swing the beam around somewhat, so that inside the second substance it makes a greater angle with the surface than before. On emerging, an equal bending occurs in the opposite direction. This bending of light waves when

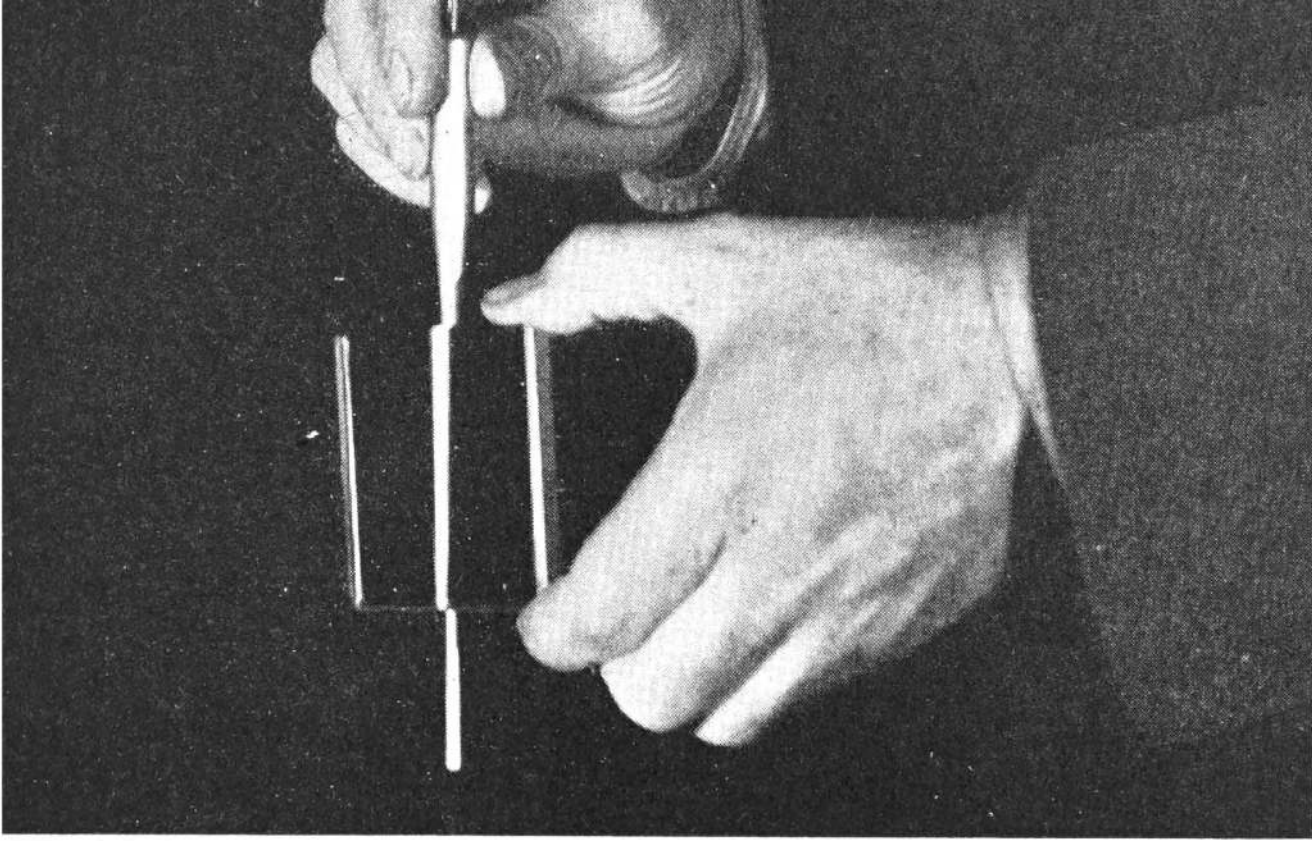
they pass from one material like air to another like water or glass is called **refraction**. The extent of the bending depends on the nature of the two substances—the one from which the light comes and the one into which it passes.

Let a narrow beam of sunlight coming through a small hole in a curtain or through a hole in a cardboard strike obliquely the surface of some water in a flat-bottomed glass. Use soapy water in order to observe better the path of the beam inside the water. The beam bends sharply where it enters the water, but bends an equal amount in the opposite direction when it leaves. The final beam is going in the same *direction* as the original, but it has been moved over sideways, as in the previous experiment. Some cigarette smoke wafted over the top surface of the water will show that part of the original light is reflected there, as from a mirror.

Would you like to increase your wealth tenfold with no risk? Then place a nickel in a glass over half-filled with water, cover with a saucer, and invert the arrangement. Looking down into the glass as shown in the diagram, you'll see a half dollar in addition to the nickel. These images are formed by refraction of light from the real coin at two sur-

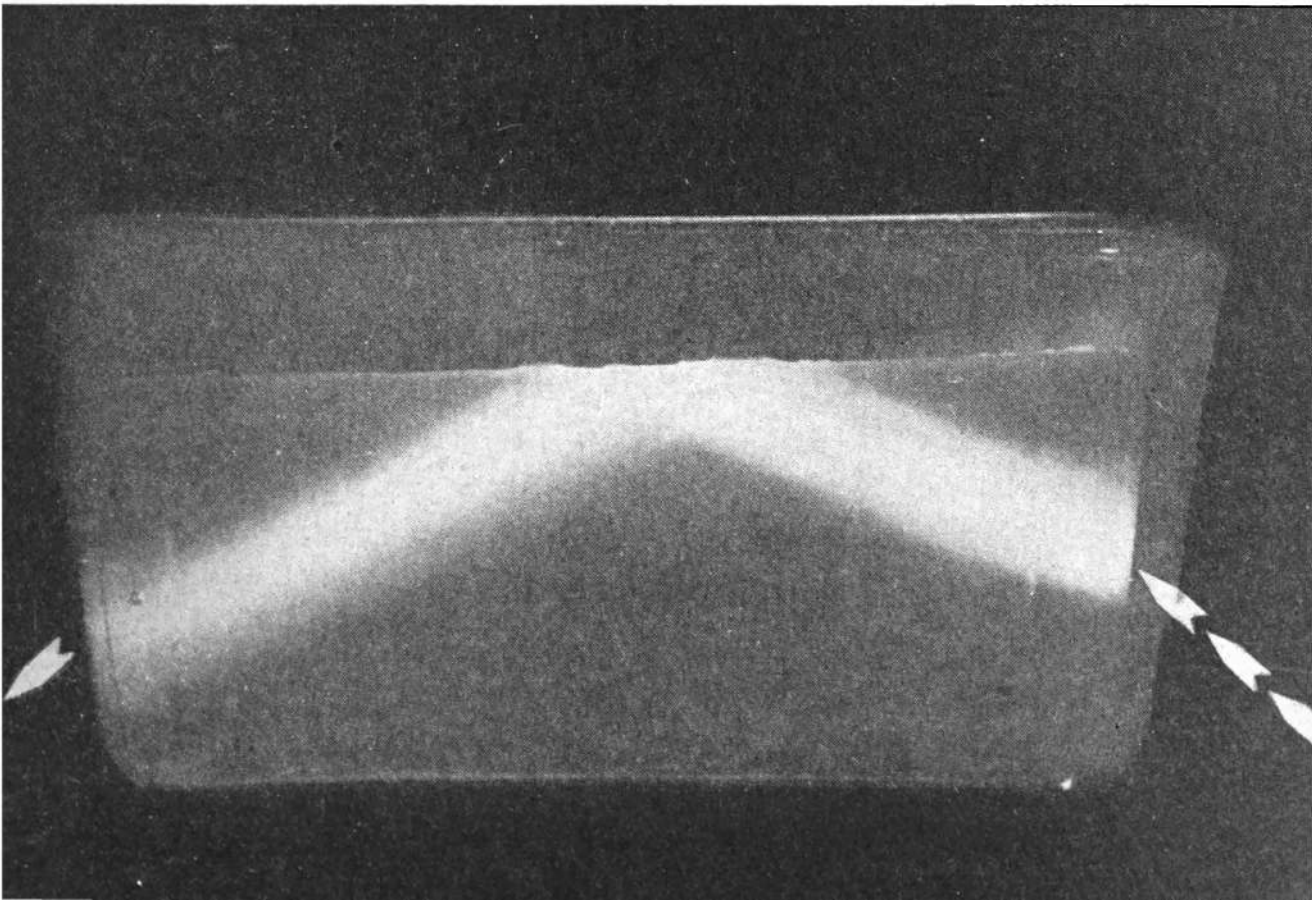


Spurious wealth



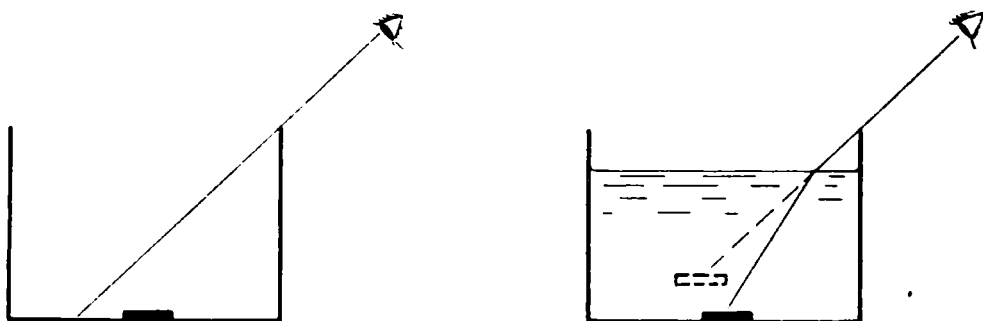
Passing through the glass, light is bent aside and the penholder appears broken

A beam of sunlight internally reflected by a water surface



faces. Notice that one seems to be lower, the other higher than the true direction of the coin. The drawing on page 188 shows the light paths.

Even better, make money appear where there was none before: Place a coin on the bottom of a rather deep pot or saucepan and place your eye in such position that the coin is just

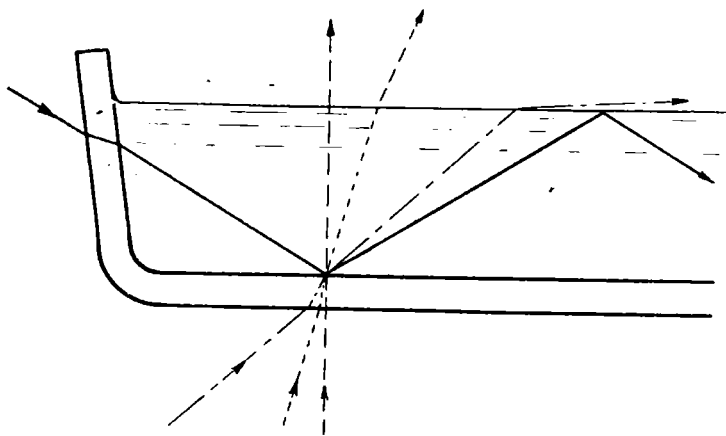


Raising money

out of sight behind the near edge of the vessel, as shown in the drawing above. Keeping your head in this position, pour water into the pan. When the water reaches the proper depth, the coin comes into view. Refraction enables you to “see around a corner” under such circumstances.

Send a narrow beam of light through soapy water from below, so that it emerges from the top surface. Do this by reflecting the original beam of sunlight into the side of the glass from a flat mirror, which can be tilted at any angle. Make the rays that strike the water surface from below come into it at smaller and smaller angles; the emerging beam will lie closer and closer to the surface as you do this, until finally, when the first ray makes an angle of about 42 degrees with the surface, the outcoming beam goes right along this surface. If you now make this angle any smaller, there is no longer any outgoing beam—all the light is reflected back into the water. This is called **total reflection**. At these larger

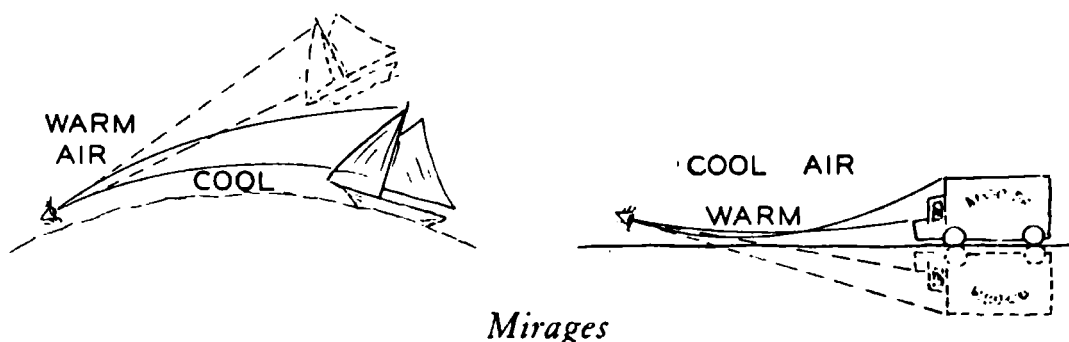
angles, it is physically impossible for any light to get out of the water.



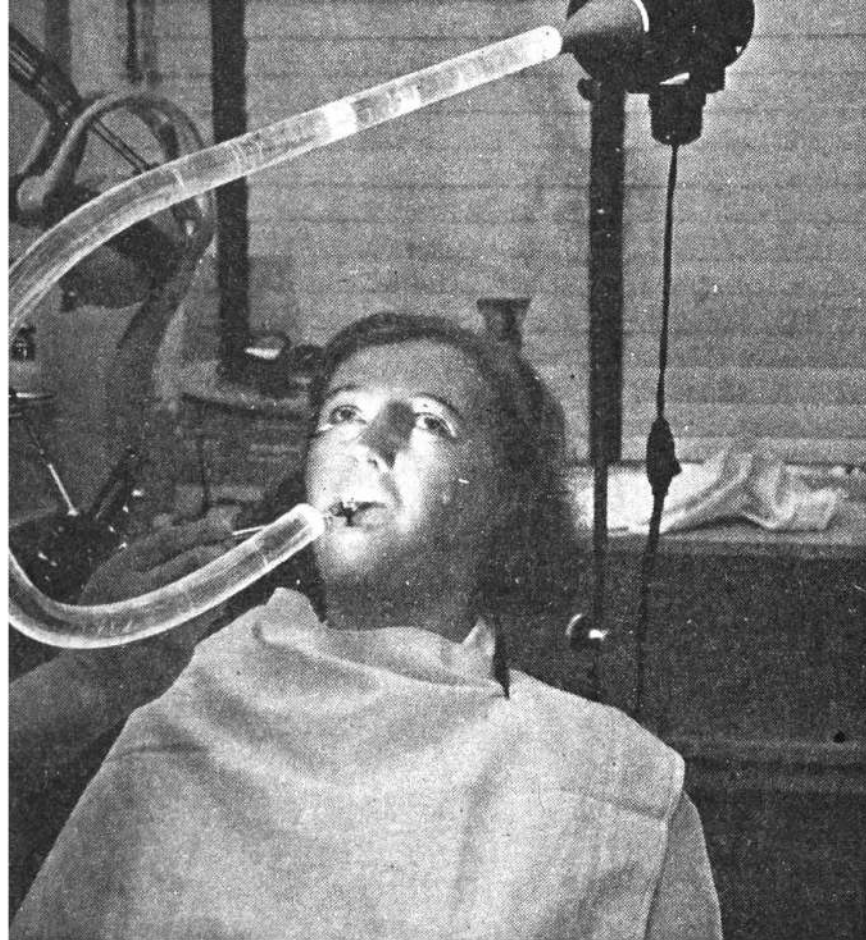
The ray entering from the side cannot emerge

Total-reflecting prisms are used in prism binoculars (page 197). The slant surface of a glass prism acts as a perfect mirror so long as the rays hit it from within at an angle smaller than about 48 degrees. A swimmer, looking upward through the water when the surface is quiet, sees the whole outer world compressed into a circle in this “fish-eye view”. The underwater rays coming through the edge of the circle make an angle of about 42 degrees with the surface. Simpler than this is the experiment of holding a glass of water overhead and looking up through the side of the glass at the surface of the water. It appears silvery, due to the light it reflects. You will even be able to see the reflection in it of a spoon standing in the glass. Light can be “piped” along a stream of water or inside a rod of transparent plastic material by total reflection. Dentists and doctors now use the latter method to obtain concentrated light without objectionable heat. Internal reflection of light makes snow crystals appear white in color, whereas we know that ice or well-packed snow is colorless. The white is merely reflected sky light.

When light goes through air that is not all at the same temperature it is refracted. This fact accounts for the twinkling of the stars, the wavering appearance of objects seen over the top of a heated surface and the occurrence of mirages and "looming." Have you ever noticed, when riding in a car on a hot day, the appearance of water on the road some distance ahead? Always, the water mysteriously disappears before you get to it. Of course, it's not water at all, but light from the sky bent up to your eye by warm air near the ground. You can even see the "reflection" of approaching cars in this way, because you judge the direction of the object to be that from which the ray comes as it enters your eye. The diagram shows how such effects come about.



The refraction of light finds its most useful application in connection with lenses,—for proof, ask anyone who wears glasses or whose hobby is photography. A lens is merely a piece of glass or other transparent material having suitably curved surfaces. The surfaces are usually parts of spheres. If the lens is thicker at the middle than at the edge, it is called a **converging** lens, because it is able to bring rays of light together to a focus. It does this by slowing up the middle part of each wave more than the outer parts, so that after going through the lens the waves close down on the focal point. If thinner in the middle than at the edge, the lens is said to be

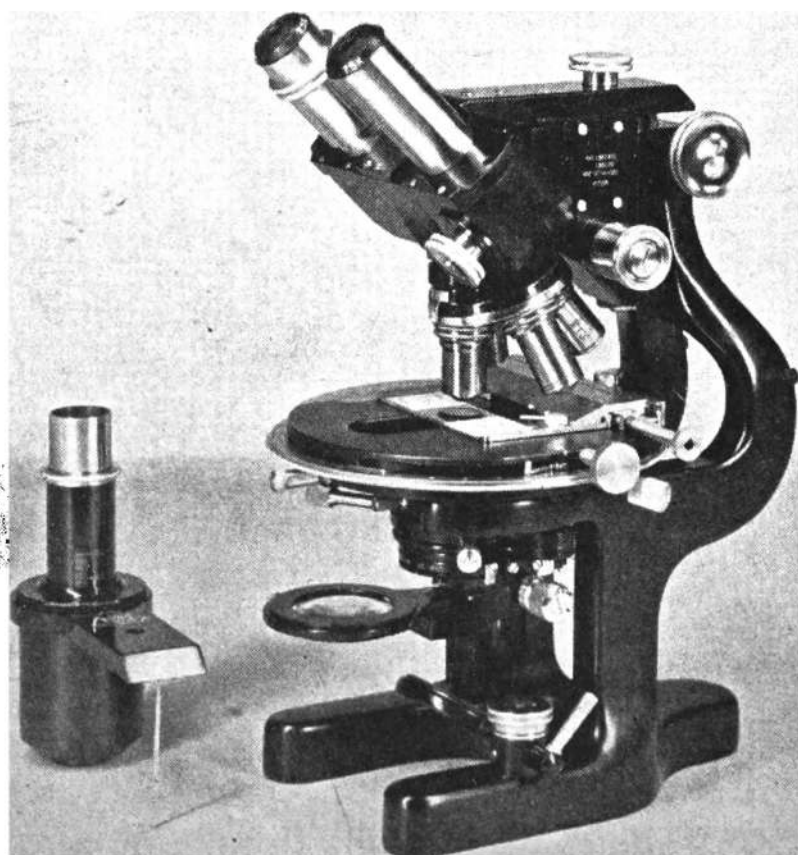


*Light
"piped" along
a transparent
rod by internal
reflection*

Courtesy Du Pont Style News Service

Courtesy Bausch & Lomb Optical

*Modern
binocular
research
microscope*

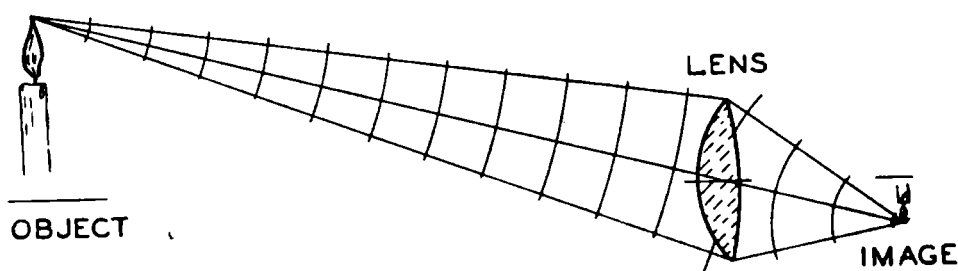


diverging; rays after passing through it are spread farther apart than before.

Converging lenses were used as burning glasses by the ancients. Even a fish bowl filled with water concentrates light in this way, but not very perfectly. A reading glass, the large lens of an opera glass, or a lens from a farsighted person's eyeglasses is better for the following experiments.

Hold a white card behind a converging lens and move the card or lens back and forth until you obtain a sharp image of a distant building. The image—a real one—is much smaller than the object casting it, and is inverted and reversed right and left. The distance between card and lens is called the **focal length** of the lens. The arrangement is the same as a photographic camera, with the card taking the place of the film. To get nearer objects in focus on the card, you must bring the lens a bit farther away from the card. This is what you do when you focus your camera. If the instrument has no ground-glass screen for checking the focus you set the lens according to a distance scale on the case.

If you don't mind a little arithmetic, you can easily compute where to put the card in order to focus sharply a given



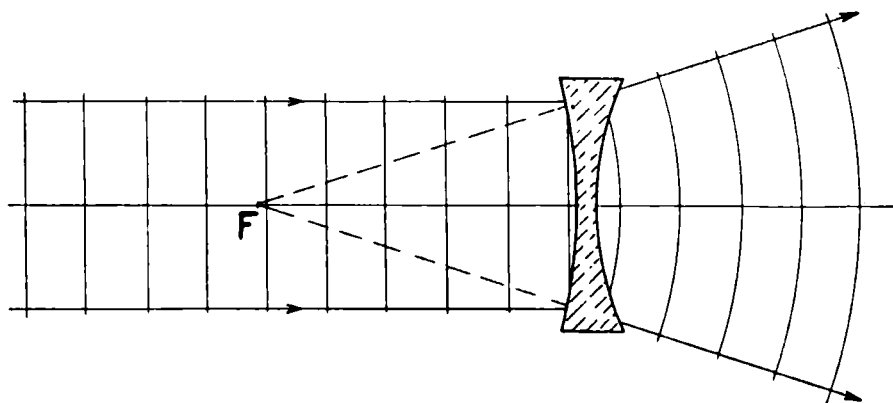
A convex lens forms a real image

object: Having determined the focal length—the distance from the lens at which a very distant object has its image—multiply it by the distance of the present object and divide

this result by the distance of the object minus the focal length. As an example, if the lens has a focal length of 6 inches, and you wish to form an image of a candle flame that is 30 inches from the lens, you will have to place the card $6 \times 30 / (30 - 6)$ or $7\frac{1}{2}$ inches back of the lens. The **magnification**—the relative size of the image as compared with that of the object—is merely the image distance ($7\frac{1}{2}$ inches here) divided by the object distance (30 inches), or $\frac{1}{4}$; that is, the image is $\frac{1}{4}$ as tall as the object. This set-up is represented approximately to scale in the preceding diagram.

The larger the diameter of a camera lens, the more light it admits and the brighter the image formed. Consequently, a lens with large relative aperture is desired by every photo enthusiast. The relative aperture is merely the focal length of the lens divided by its diameter. An $f/4.5$ lens is one whose focal length is $4\frac{1}{2}$ times its clear diameter. Used “wide open,” it admits 4 times as much light as when “stopped down” to $f/9$; 16 times as much as when the diaphragm is closed down to $f/18$.

Unscrew the eyepiece of an opera glass and try to obtain an image of the sun or of a lamp by holding a card behind the lens. Instead of an image, you will observe only a circle of uniform light, for this type of lens is unable to form real



Light diverges after passing through a concave lens

images. All the rays leaving the lens appear to come from a virtual focal point lying on the same side of the lens as the source. Diverging lenses are used in optical instruments only in combination with converging lenses, or as spectacle lenses for nearsighted persons. You'll imagine yourself in Lilliput when you look at your surroundings through the eyepiece lens of an opera glass, or when you look through the complete instrument held wrong end to your eye.

• **Cylindrical** converging lenses are useful, especially in correcting faults of the eye (see page 226). These lenses, unlike regular (spherical) converging lenses, have a curvature in one direction only. A glass of water is such a lens. Look through it and notice that objects on the other side have the same type of sidewise distortion that you observed when looking at your reflection in a spoon. The front of a thermometer stem forms a cylindrical lens, making the hair-fine mercury thread appear wider so that it is more easily seen.

If you have at hand two or three converging lenses of different focal lengths, you can use them to construct useful optical instruments. First, to use a single converging lens as a simple magnifier, hold it as close to your eye as convenient, and bring the thing to be examined up to about the focal distance from the lens, where it will be seen distinctly. The crude instruments used by ANTON VAN LEEUWENHOEK, pioneer of the microscope, were just such simple lenses. The shorter the focal length of the lens, the greater its magnifying power. Check this by trying different lenses in turn. A simple lens or combination of such lenses forms the eyepiece of a telescope or a microscope. Lacking a glass lens, you can use a drop of water as a magnifier. Place the drop on a small hole in a piece of wood or metal or on a loop of wire. Surface tension gives the drop the form of a short-focus lens.

To construct a **refracting telescope**, simply fix a long-focus and a short-focus lens a distance apart equal to the sum of their focal lengths, with the former pointed at the distant object, the latter in front of your eye. For convenience, mount the lenses in the ends of two paper or cardboard tubes sliding one inside the other, using gummed paper or scotch tape to hold the lenses in place. The **reflecting telescope** previously described used a concave mirror in place of the long-focus convex lens. The magnifying power of any telescope is approximately the focal length of the front lens (or mirror) divided by that of the eyepiece. Note that the images are always inverted. A prism binocular is merely a pair of refracting telescopes, one for each eye. Compactness is secured by sending the light back and forth inside the tube, using total-reflecting prisms for the purpose.

The **opera glass** gets around the inconvenience of the great tube length of a telescope by using a short-focus diverging lens as eyepiece. You can make your opera glass twice as powerful by unscrewing both eyepieces, placing them together and holding the pair at twice their former distance from the front lens. The first astronomical telescope, devised by GALILEO early in the seventeenth century, was really an opera glass. Shortly thereafter KEPLER constructed the first astronomical refracting telescope. Still later NEWTON invented a form of reflecting telescope.

Two converging lenses of rather short focal length are required in order to set up a **microscope**. Mount the lenses in draw tubes if possible and set them initially a distance apart equal to four or five times the focal length of either one. If the two have different focal lengths, the lens of longer focus should be the eyepiece. Bring the front lens up toward a brightly illuminated object—a hair, an insect, a postage stamp

—until it is not much farther away than its focal length, then slide the eyepiece in until the object when seen through the combination appears in sharp focus. If necessary, use a concave mirror or converging lens to concentrate light on the object. Notice that the image seen in the microscope is inverted; this seems to be characteristic of many optical instruments.

It's a simple matter to find the magnifying power of a microscope: With one eye, look at a ruler through the instrument; with the other eye, look directly at this object, and note how many divisions seen with the unaided eye correspond to one space seen through the microscope.

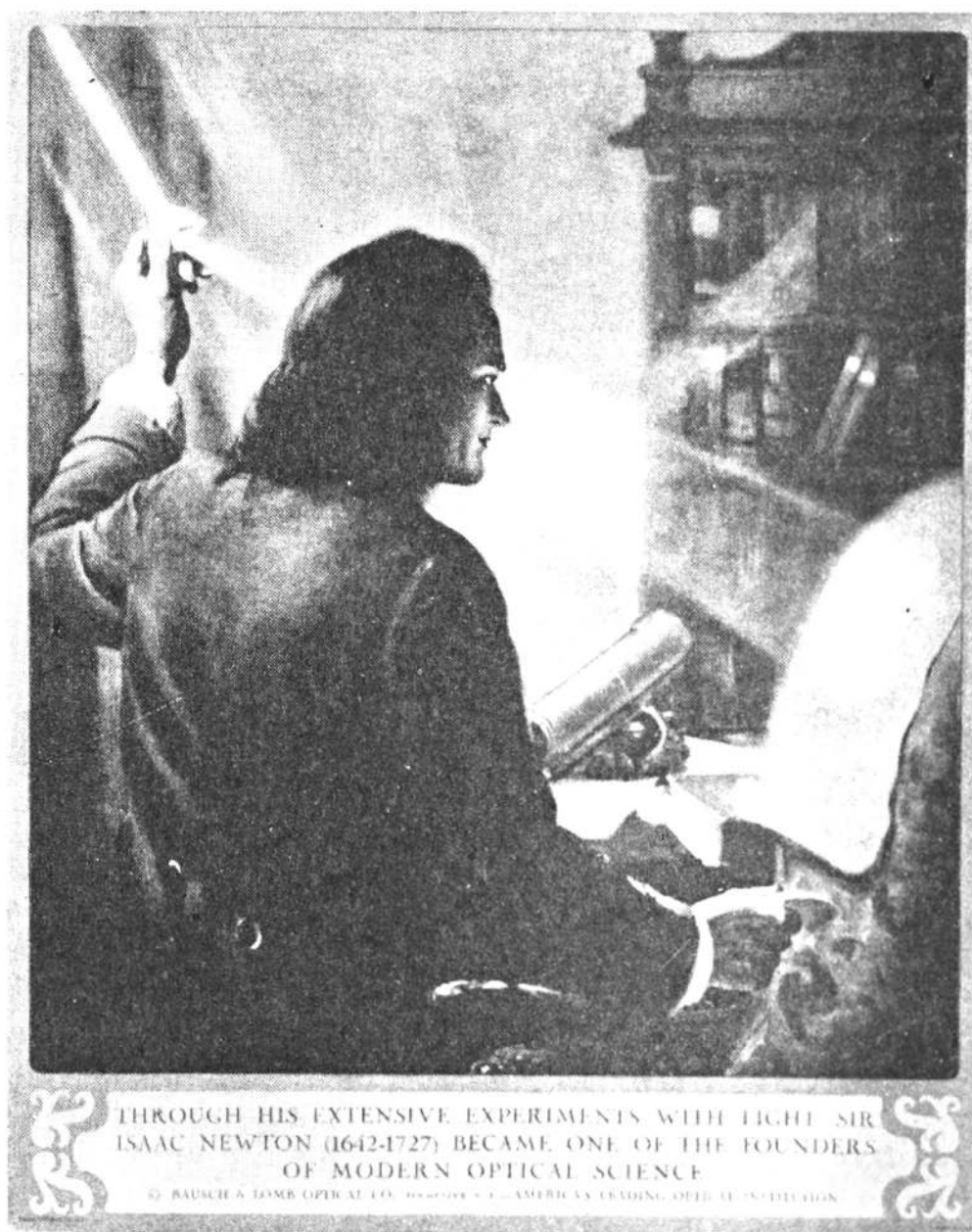
The science of microscopy has come a long way since the first efforts of the Dutch opticians of the sixteenth century. Bacteriologists and metallurgists now have available instruments of great power and precision, and magnifications of as much as 10,000 have been attained. This amounts to making a pinhead appear to be 50 feet across.

19

BEYOND THE RAINBOW

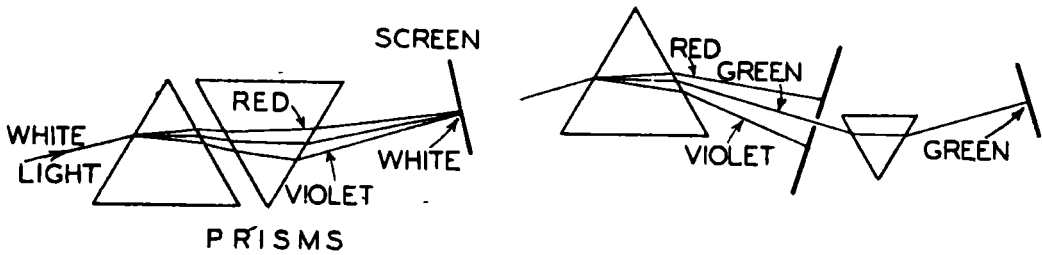
WHILE NEWTON was a student at Cambridge he performed a simple experiment that revealed for the first time the true character of the colors we see in the world about us. Holding a triangular glass prism in the path of a narrow beam of sunlight, he found that the rays were spread out fanwise after passing through the prism. But the surprising feature was that the transmitted light formed a beautifully colored rainbow—the red at one end merging into orange, then yellow, green, blue and violet by imperceptible gradations. Where do these colors come from? NEWTON suspected that they were all present to begin with in the beam of sunlight, and that the total impression received by the eye from this mixture was sunlight—what we call technically **white light**. In passing through the prism the various colors were refracted, but by slightly different amounts: The violet rays were bent aside most, the blue a little less, the green still less, and so on. Once spread out in this way, the eye is able to recognize each color for what it is. The rainbow sequence of colors is called a **spectrum**.

To test his idea of the nature of white light NEWTON placed a second prism behind the first, but reversed in position, and found that the rays were re-united into a colorless patch of light. Not yet satisfied that he had found all the essential facts, he removed the second prism, cut a small hole in the card on which he cast the spectrum, and placed the second prism behind this opening. His idea was to see if the single



Courtesy Bausch & Lomb Optical Co.

color coming through the hole could be broken up further by the second prism. Nothing of this kind occurred; green light coming through the aperture and penetrating the second prism was bent aside by it, but the transmitted light still possessed the same green hue as before. The two experiments are shown diagrammatically in the accompanying figure.



White light is a mixture of colors

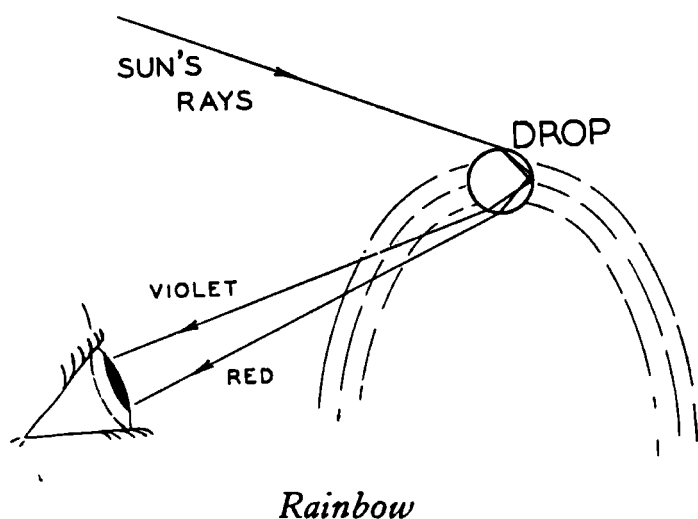
It is hard to appreciate the importance of these experiments of NEWTON's. Their consequences are responsible for a great deal of what we know about the physical world—not only about light itself, but about the very nature of atoms and molecules. Certainly, these pioneer experiments performed by the young NEWTON in his lodgings at Trinity College deserve to rank among his greatest works.

Once a NEWTON has pointed the way, you and I can repeat the same tests for ourselves. In the absence of a regular glass prism (a small one can be bought very cheaply), use the beveled edge of a cut glass article or a crystal glass pendant, or make a water prism by supporting a flat-bottomed glass vessel partly filled with water in an inclined position. Simply looking at a lamp or a brightly lighted object through the prism will show the color effect, or **dispersion** of light; the object appears fringed with vivid color—violet on one side, red on the other. To repeat NEWTON's experiment of projecting the spectrum, merely hold the prism in the path of a narrow sunbeam entering through a slit in the window curtain. Use a white card to receive the spectrum. In the absence of sunlight, place a lamp behind a narrow horizontal slit cut in a card, fix a rather long-focus lens at a distance away just greater than its focal length, and place a card at the proper distance to receive a sharp image of the slit. Now place the prism just beyond the lens, its refracting edge up, and the

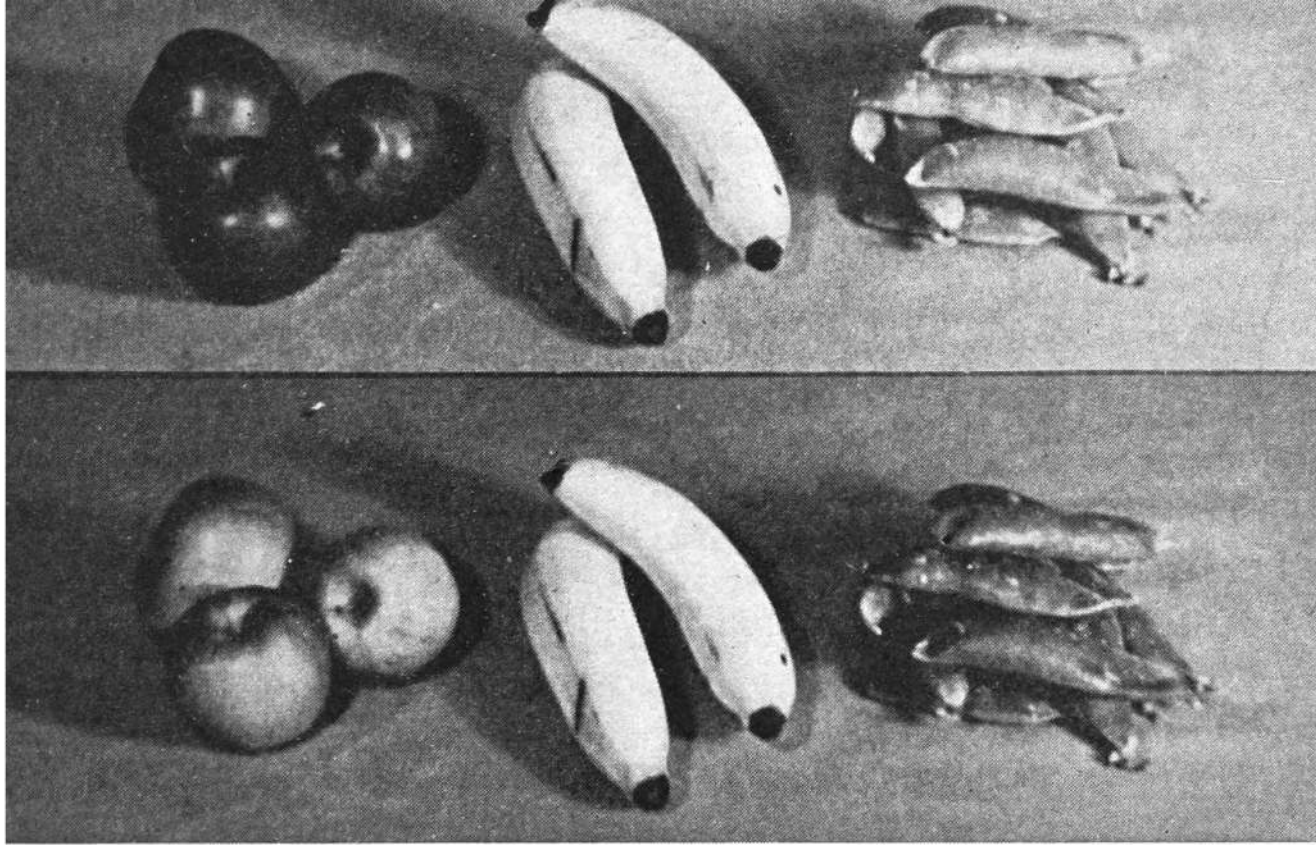
white slit image will give way to a colored spectrum which lies below it on the screen. The colors can be recombined to give a white spot of light by using another lens or a concave mirror to bring them together.

Because different colors are bent by slightly different amounts, there is some separation of color whenever light passes through any transparent substance. A lens acts to some extent like a prism, and color effects are visible, especially around the edges. For purposes such as photography, all colors should be bent equally, so that all come to the same sharp focus. This can be realized by using combinations of lenses made of different kinds of glass.

Sunlight, passing through myriad droplets of water suspended in the air after a shower, is dispersed to give the familiar phenomenon of the rainbow. The light is refracted when it enters the drop, totally reflected from the back sur-



face, and refracted once more as it emerges; but while going through the drop it is also dispersed, so that the several colors come out at slightly different angles and thus reveal themselves in the striking spectacle of the rainbow.



*Apples, bananas and green peas illuminated by green light (above),
and by red light (below)*

Throw a spectrum on a screen, using a prism as above. Now deflect part of the light that forms the spectrum to one side by inserting a narrow piece of mirror glass or a knife blade into the the spectrum at some point. Use lenses to reunite both the original and the deflected parts. Each of the two spots of light thus produced will be colored. The two colors are said to be **complementary**. Depending on where the small mirror is inserted, the colors will be red and sea green, orange and blue, or yellow and violet. If you now unite the two complementary spots, the result is again white light.

The color of a material object is due to its ability to **absorb** light of certain colors and to **reflect** all the rest. An apple looks red when seen by ordinary daylight, because the pigments in its skin can absorb the other colors, leaving only the red to be reflected to your eye. The same apple seen in red light appears whitish in color because it reflects nearly all the

light falling on it. In green light, it appears very dark or nearly black, because it is unable to reflect much green, and so sends virtually no light to your eye. Examine the appearance of various colored objects, such as pieces of paper, in light that has come through sheets of colored glass or several layers of colored cellophane. Colored letters on a white card fade into the background when viewed in light of the same color.

Try also the effect of placing these color filters, one after another and also in combination, in the path of light entering a prism. Notice that insertion of a filter cuts out a certain range of colors, and that the colors remaining often differ from the apparent color of the filter. You may find, for example, that what appears to the eye to be a green glass lets through not only the green part of the spectrum, but considerable yellow and blue as well.

Paints, too, owe their characteristic appearance to the absorption of certain colors. Every painter knows that a mixture of blue and yellow pigments is green. That's because blue paint absorbs almost everything but green, blue and violet, while yellow paint absorbs all but green, yellow and red. The mixture, then, appears green because that is the only hue that neither part can absorb.

The chemical processes that go on in growing plants require the red light of the sun's rays. As long as the plant is alive, red is absorbed by a substance in it called **chlorophyl**, and so the remaining colors—largely green—are reflected, giving the plant its characteristic color. The colors of flowers, too, are the result of absorption by complex chemicals contained in them.

Light, as you already know, consists of waves. After NEW-

TON's time it was found that what the eye perceives as difference in color is really difference in the length of the waves. Red light has the longest waves. The other colors have shorter and shorter waves in the same order as they occur in the spectrum, violet waves being about half as long as the red. The waves of visible light, unlike water waves or sound waves, are extremely short. It takes over 30,000 of the longest visible red waves to extend a distance of only an inch, while more than twice this many extreme violet waves fit into the same distance. When waves lying between these limits strike the eye, they produce the sensation of sight. All wave lengths (colors) of light travel through empty space with the same speed—about 186,000 miles a second; but in glass or water, violet light travels more slowly than red, and the speeds of the other colors are intermediate. It is this difference in speed that causes the colors to refract differently when they pass through a prism, spreading out into a spectrum.

Darken the kitchen, place a pinch of salt or soda on the end of a screwdriver or a piece of tin and hold this end in a gas flame. Even the tiniest speck (page 20) of salt will make the colorless, almost invisible flame take on a strong yellow glow, and the whole room will be illuminated with a weird, unnatural light. Colored objects exhibit a peculiar appearance, and the skin assumes a startling, deathly hue. The yellow color is due to the vapor of the chemical element sodium, one of the constituents of common salt. If you were to pass the light from this flame through a prism you would find that, unlike sunlight or the light of an electric lamp, only *one* color is present in the spectrum—a narrow region in the yellow part of the spectrum and nothing else. Any chemical that contains sodium gives light of this same color,

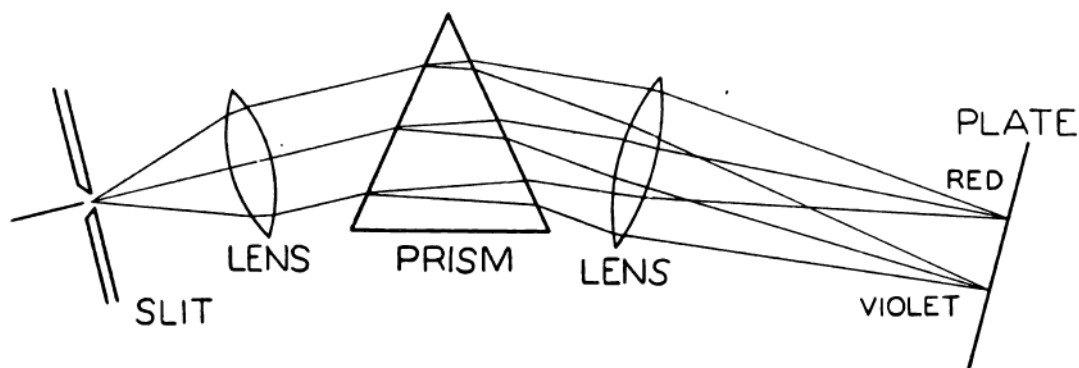
regardless of what it may be mixed with or combined with. The waves of yellow light coming from a sodium-fed flame are about 23 millionths of an inch in length.

In the same way, a little cream of tartar or saltpeter introduced into the gas flame gives it a peculiar lilac color, and the light given off is found to consist of only two rather definite wave lengths—one in the red and another in the violet. Compounds of calcium give an orange-red flame, barium a vivid green, etc. In each case, definite wave lengths of light are emitted.

At about the time of our Civil War, two scientists at the University of Heidelberg, the chemist BUNSEN and the physicist KIRCHHOFF, examined the spectra of a large number of chemicals and found that the wave lengths of the light emitted were characteristic of each substance, and so could be used to identify it without resorting to the usual inconvenient and time-consuming methods of chemical analysis. It is only necessary to vaporize the unknown substance in a flame, or better in an electric arc or spark. If it is a gas, it may be put into a vacuum tube and made to glow by passing a high-voltage current through it. Then some of the light from the substance is passed through a prism and the exact nature of the spectrum is noted. Once this has been done for a large number of materials, the spectrum of an unknown mixture can be identified readily.

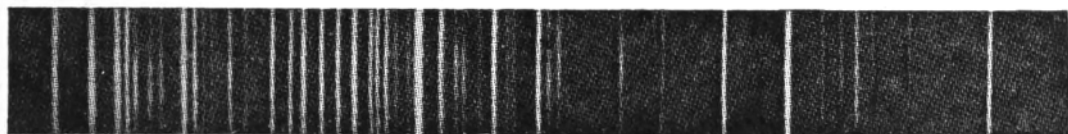
But first the prism arrangement for analyzing the emitted light must be improved somewhat. In place of a round hole to admit the light, a narrow slit perhaps less than a hundredth of an inch wide is used. This prevents overlapping of colors in the final spectrum. Lenses are placed both before and after the prism, and the spectrum is examined with an eyepiece. The complete device is called a **spectroscope**; it is

one of science's most powerful and versatile instruments. If a permanent record is wanted, the eyepiece is omitted and a photographic film or plate is put in the focal plane of the second lens. The instrument is then called a **spectrograph**.



Spectrograph—it analyzes light

Each wave length of light from the source is represented on the film by a sharp line—an image of the slit. Several of these lines may fall in each color region of the spectrum. On the film, these colors do not show; the only important factor is the arrangement—the relative positions—of the lines.



Each substance has a characteristic pattern of spectrum lines

Shown here is the spectrum of the chemical element potassium

Of course, the details of this so-called **spectrochemical analysis** are complicated, but the underlying principles are not hard to understand. The entire procedure depends on the fact that the atoms of a given chemical element always emit a definite set of wave lengths of light when stimulated by heat or by electricity. There must be something in an atom that is capable of vibrating some million billion times a second to emit waves of visible light. A great deal of ingenious and

painstaking research during the last half century has finally revealed that the things that are executing these super-fast vibrations are electrons, which are part of all atoms.

The electrons in a given atom can vibrate only in certain prescribed ways, giving rise to a definite set of wave lengths of light. This is true only so long as the various atoms of the material are independent of each other—that is, when the substance is a gas. In a solid substance, neighboring atoms jostle each other, and their characteristic waves are blurred into a jumble consisting of all possible wave lengths. The resultant spectrum no longer consists of a set of definite lines but is now a *continuous* band of color extending from red to violet, like the rainbow or the spectrum of a lamp filament.

The study of spectra has made the whole universe one great science laboratory. It has revealed the chemical nature, the temperature, the distances, the motions of remote stars; it enables us to look—indirectly, of course—into the very heart of the atom. During recent years it has been found possible also to determine the approximate *amount* of each substance present from a measurement of the brightness of the spectrum lines. This **quantitative** spectrochemical analysis is proving extremely valuable in the glass and metal industries, in crime detection, etc.

It is the property of the human eye that we are able to see only those waves of light whose length lies between about $1/60,000$ and $1/30,000$ of an inch, but there are other waves of a similar nature, some shorter and some longer, which differ from visible light only in the methods by which they can be produced and detected.

If the spectrum of a powerful arc light or of the sun is cast on a screen, it is found that there are waves falling on that part of the screen which extends beyond the violet and also

on the part beyond the red. The waves on the violet side are found to be shorter than the extreme violet ones; they constitute the **ultra-violet** region of the spectrum. The waves adjoining the red end of the visible region are said to belong to the **infra-red**. Some of each is present in sunlight. The ultra-violet rays, like the visible ones, can be detected readily by means of a photographic film.

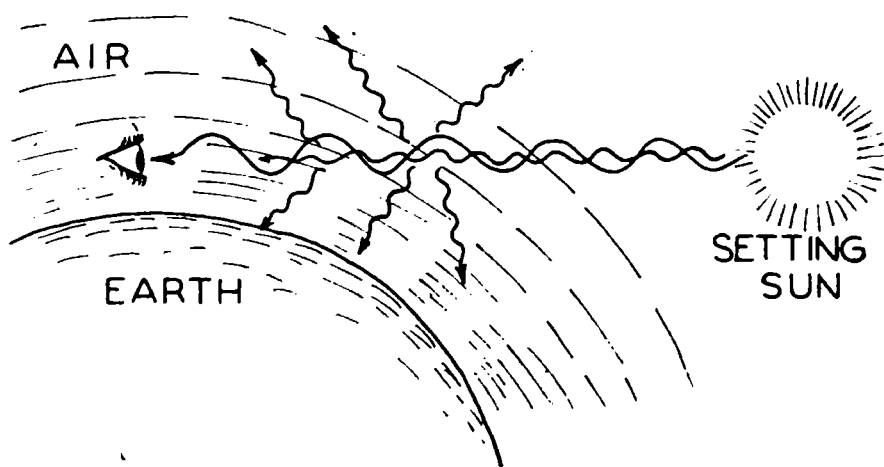
Another way to detect the ultra-violet radiation in the spectrum is to coat the part of the screen beyond the violet with vaseline, which glows with a soft, bluish light when these rays fall on it. The invisible ultra-violet rays are converted into longer, visible radiation by the molecules of this substance. The process is called **fluorescence**. Kerosene, machine oil and certain minerals like zinc sulphide show fluorescence under the influence of even visible light. Look at the surface of some lubricating oil in a glass and observe the blue tint, which is due to fluorescence.

The earth's atmosphere cuts off (absorbs) all waves shorter than about $1/100,000$ of an inch before they reach the ground. These rays, partially absorbed in the upper atmosphere, produce ionization and other important effects (page 180). The ones that succeed in coming through are equally important; they are responsible for killing bacteria, causing sunburn, producing vitamins, etc. One of the most commonly used sources of ultra-violet light is the mercury-vapor lamp. The spectrum of mercury has strong lines in this region.

The infra-red radiation that falls just beyond the red end of the visible spectrum can be detected by holding the blackened bulb of a thermometer at that part of the screen. The rise in temperature indicates the fact that radiation is falling there. Infra-red rays are emitted not only from glowing objects, but from bodies at all temperatures (page 117). The

higher the temperature, the greater the amount of short waves given off. For example, when a piece of metal is warmed in a flame it appears dull red in color when it first begins to give off light of its own. As its temperature goes up it becomes orange, yellow, and finally white hot as more and more of the shorter waves are added. The temperature of the sun or of a star can be determined by measuring the distribution of brightness in its spectrum.

Besides permitting of detection by the heat they produce, infra-red rays of wave length up to $1/20,000$ of an inch can be recorded photographically on special plates now available. In this way, pictures may be taken in total darkness—truly, black magic! But one of the most useful applications of infra-red photography depends on the fact that these rays penetrate fog, smoke and haze, revealing the details of landscapes hundreds of miles distant. Their greater penetrating power



Scattering of light makes the sunset red

is due to the fact that these long waves are **scattered** less by small particles in the air than are the shorter visible waves. The sun and moon appear red when low in the sky because then their rays pass through a greater thickness of air, result-



Courtesy Ohio State University

*Landscape photographed by ordinary light (above) and
by infra-red light only (below)*



Courtesy Ohio State University

ing in the scattering aside of the short waves (blue), and leaving the longer waves (orange and red) to come through to your eye. The scattered radiation is what gives the sky the characteristic blue color it has when viewed in any direction away from the sun. It is scattered light that enables you to see the beam of a searchlight when off to one side of it. Notice also, the next chance you get, that the beam is more readily seen when the air contains smoke or haze, and that the scattered light is bluer than the direct beam. The blue of the sea, or of smoke rising from a cigarette, is due to scattering of visible light by small particles.

We have not yet considered all the radiations that exist. Shorter still than ultra-violet waves are the **X-rays**, discovered by ROENTGEN in 1895. As you know, a special type of vacuum tube is required in order to produce them. Their outstanding property is the ability to penetrate considerable thicknesses of most materials, revealing flaws in castings, alterations in paintings and documents, the internal structure and condition of parts of the body, etc. The results of such examinations are usually recorded photographically. Equally important is the value of X-rays in treating cancerous growths and diseases of the blood.

Even shorter and more penetrating than X-rays are the so-called **gamma rays** given off when atoms of radium and similar elements spontaneously break up. The atoms of a dozen or so of the heaviest chemical elements are so complex in structure that they occasionally explode, releasing fast-moving charged particles and, in addition, penetrating rays of the same general nature as X-rays, but of smaller wave length. The uses and methods of detection are in general the same as for X-rays. Recent "atom-smashing" experiments make it possible to produce artificial radioactivity in a number of

substances, including common salt, solutions of which may be injected directly into the tissues to be treated.

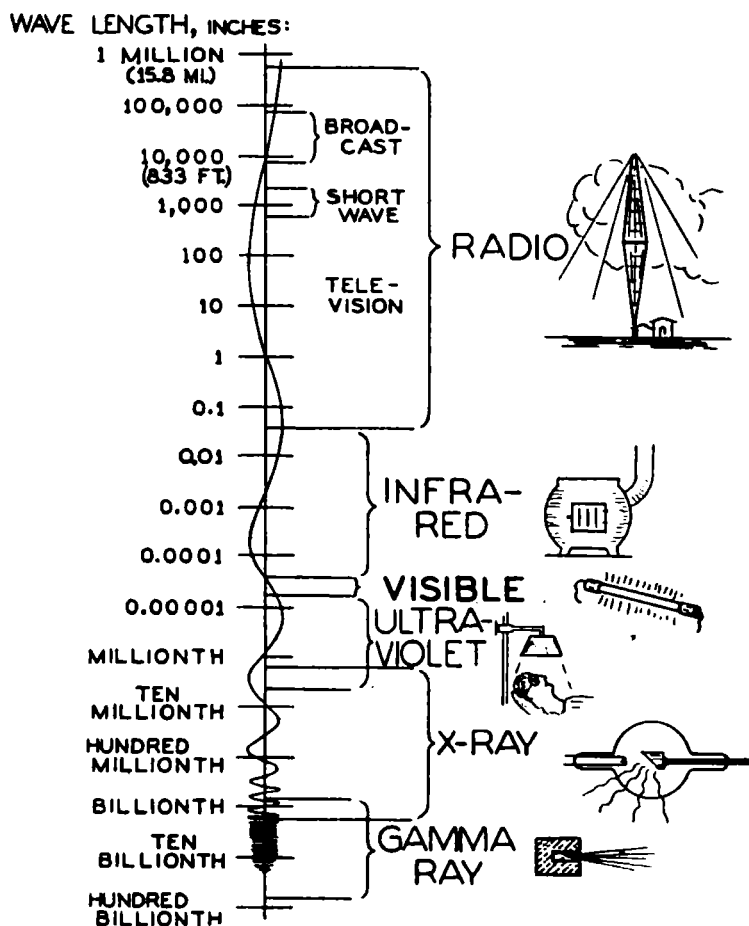
You can observe, indirectly, the disintegration of individual atoms of a radioactive material if your watch has a luminous dial. After resting your eyes in a completely darkened room for several minutes, look at the luminous figures on the dial through a short-focus lens or lens combination (the combined focal length should be less than an inch). In place of the soft, uniform glow seen with the unaided eye you will now see pin-point flashes of light—scores of them at one time. The luminous paint consists of a fluorescent substance like zinc sulphide mixed with tiny amounts of a radioactive material. What you see are the flashes produced when, here and there, an atom of the latter disintegrates. The immediate cause of the fluorescence is the throwing out of a high-speed particle from the core of the radioactive atom.

Gamma rays whose wave length is about 7 million times shorter than visible light have been produced. No shorter “light waves” than these are known. **Cosmic rays** and **neutron rays**, once thought to be waves, are now known to consist of fast-moving particles of matter.

Finally, completing our story of radiation, are waves that lie on the long-wave side of the infra-red region. The waves in question are produced and detected by electrical circuits in which alternating currents oscillate back and forth a million or so times each second. They are commonly called **radio waves**. Those used in regular sound broadcasting are several hundred yards in length, while the wave lengths used in television broadcasts are about ten yards long.

All of these types, from the shortest gamma rays to the lengthiest radio waves, are of the same essential nature; all behave like light, and can be reflected, refracted, etc.; all

travel through empty space with the speed of light—186,000 miles per second. Some points of information about the complete **electromagnetic spectrum**, as it is called, are summarized in the accompanying figure, which deserves a few minutes' inspection.



Light—visible and otherwise

Up to now we've been taking for granted the fact that light travels in straight lines. Indeed it does in most cases, but there are situations in which this is no longer true—where light can actually bend around corners to some extent. It does this when it grazes the edge of an obstacle or passes through small openings. This ability to deviate from the

“straight and narrow” is possessed by sound waves and by water waves, too. In fact, it is said that the Dutch scientist HUYGENS first hit upon the notion that light consists of waves by noticing that sea waves entering an opening in a break-water spread out sidewise after coming through. You can show the same thing on a smaller scale in a ripple tank by sending waves through the space between two barriers.

You may not have given it much thought, but certainly you know from experience that sound waves bend around objects in their path. That’s usually how you hear sounds from an adjoining room. Holding a large cardboard between a source of sound and your head doesn’t cut off the sound, much as you might wish this to be true when another member of the family is listening to his favorite radio program.

Your ripple tank experiments will show one thing more: The smaller the aperture is, compared with the length of the waves, the more they are bent. This is true for all sorts of waves. Since light waves are very tiny, the openings must be very small in order to produce this bending or **diffraction**. Look at a distant light through the narrow space between two fingers held lightly together. Bring the fingers closer. See how the light source broadens out, bands of light appearing behind the fingers, where they do not rightly belong. Squinting through the eyelashes or looking through a feather produces the same effect.

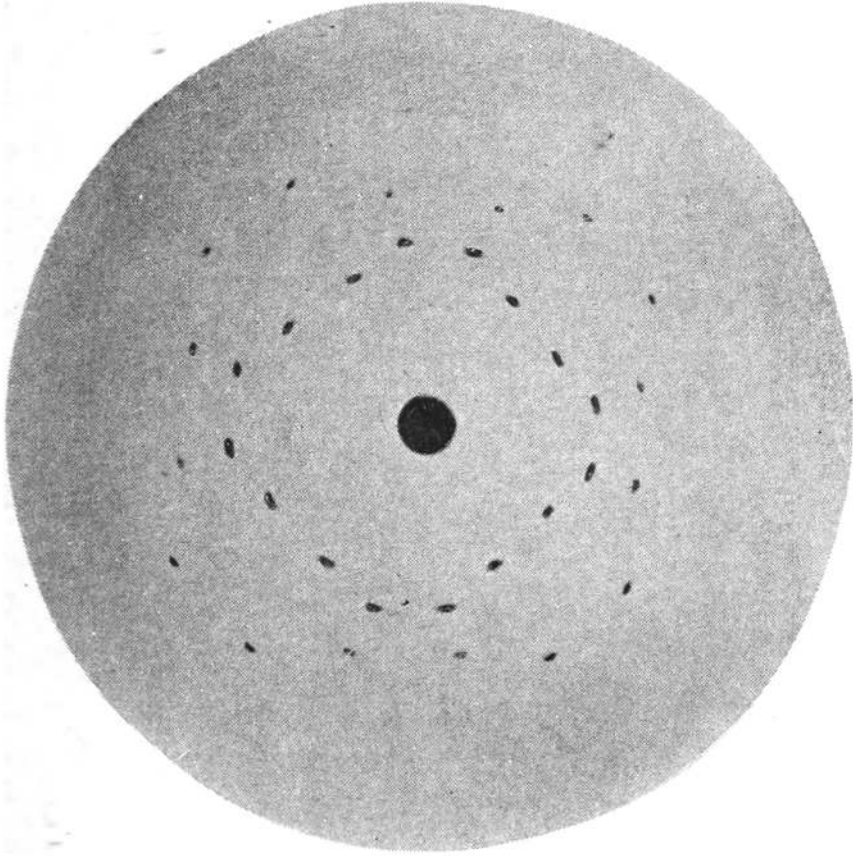
Hold your finger horizontally in front of one eye and look at a distant object lying just above it. Raising the finger slightly, you see the object apparently move upward too. The same thing happens when you look at a window through a small hole in a card. The rays near the edge of the hole are bent, and you judge their source to lie in the direction of the ray that enters your eye.

Let a candle or small unshaded lamp shine through a doorway into a dark adjoining room so that it illuminates a pencil held vertically by sticking its point into an eraser, throwing a shadow of the pencil on a wall or card a few feet beyond. Standing near the candle, move a book or card side-wise so that its shadow moves across that of the pencil. The latter will still be visible against the former; all it does is to move aside slightly as the shadow of the book crosses it. The experiment shows that some light is bent into the shadow cast by the book.

Examine a distant street lamp through a silk handkerchief or a silk umbrella. In place of a single spot of light you see a square arrangement of fainter, smeared-out images due to diffraction of light by the two sets of threads in the fabric.

The iridescent, rainbow play of colors that you see when sunlight is reflected almost edgewise from a phonograph record, a piece of mother-of-pearl, or the inside surface of an engine-turned watch case is due to the fact that various colors are bent by different amounts when thrown back from the regularly spaced ridges with which the surface is covered. In fact, a much finer set of evenly spaced ridges can be used as a substitute for the prism in a spectroscope to separate out the various wave lengths present in the incoming light. Such **diffraction gratings** are made by special machines that rule ultra-fine scratches on metal or glass plates by means of a diamond point. A good grating of this kind may have 15,000 to 20,000 scratches to the inch, and is a marvel of mechanical art. As fine as such an optical grating is, it would be too coarse for the much shorter X-rays. But Nature herself provides ready made gratings for this purpose,—crystals of certain minerals. In a crystal the atoms are arranged in regular order, providing a three-dimensional grating capable of diffracting X-rays.

Using X-ray of known wave length, the exact arrangement of the atoms in a crystal can often be determined.



The spot pattern produced by X-rays passing through a crystal reveals the arrangement of its atoms

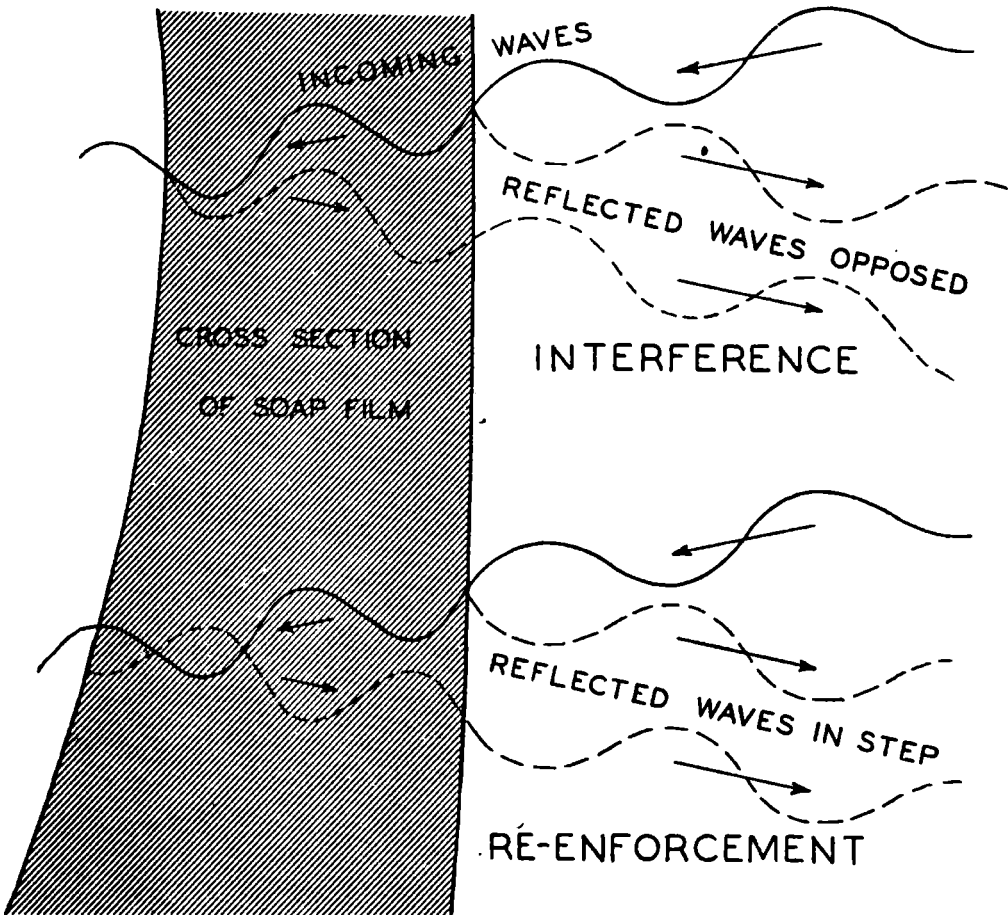
Everybody has at one time or another marvelled at the wonderful play of color shown by a soap bubble or a spot of oil on a wet pavement. An imaginative but unscientific person once suggested distilling the oil to extract the colored dyes! The coloration in these cases is not due to dyes or pigments but to what is known as the **interference** of light—a phenomenon not essentially different from diffraction. It depends on the fact that two sets of light waves arriving at the same point will co-operate or add up their effects if they arrive there in step, but will interfere or nullify each other if

they get there out of step—a case of light added to light producing darkness at certain points. This behavior is easily seen when two sets of water waves cross through each other. Where crest meets crest the water splashes up to an unusual height; wherever two troughs arrive together a momentary depression forms; at places where a crest of one set meets a trough of the other, the water is quite level because the two cancel. The versatile and gifted THOMAS YOUNG, discovering the principle of the interference of light at the beginning of the last century, saw it to be an undeniable confirmation of the idea that light consists of waves.

The best way to see the interference colors on a soap film is to look at the light reflected from it, rather than to look through it. A ray of light striking such a film divides into two parts; one is reflected from the front surface, the other enters (see figure). The ray that goes in is further split at the second surface, part emerging, part turning back and rejoining the original reflected ray. Now if the two reflected rays, after going their respective paths, reunite exactly out of step with each other, there is interference—they nullify each other and no light of this wave length reaches your eye from this point of the film. Whether there is such destruction or not depends, of course, on the wave length of the light and on the thickness of the film at that point. On account of the fact that white light consists of many wave lengths, and because a soap film is not of uniform thickness, the result is a variety of colors, each one being white light *minus* the particular wave length that is cut out by interference.

Secure two strips of clear plate glass (pieces cut from an old photographic plate) an inch or so in width and a few inches long. Fasten their ends together with rubber bands, separating them slightly at one end by inserting a strip of

thin paper. Soak a piece of blotting paper in strong salt water and hold the edge in a gas flame. Look at the reflection of the yellow flame in the pair of glass plates and it will be seen to be crossed by a series of evenly-spaced dark stripes. These dark places are the result of interference between the waves



Beautifully colored, yet it has no color of its own

reflected from the front and back surfaces of the "wedge of air" between the plates. The alternate reinforcement and interference by varying thicknesses of film is quite similar to the resonance effects that organ pipes show for sound waves (page 97).

A very slight change in the thickness of a film makes the

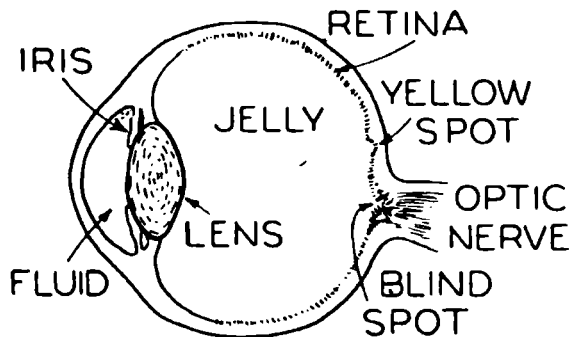
interference stripes move a great distance along the plates, as you can see by squeezing the plates more tightly together at one end. Such an arrangement, then, serves to magnify very small motions or changes of position. The various forms of this device are called **interferometers**. They can measure changes in position of the order of a millionth of an inch.

20

LIGHT AND SIGHT

“If you ever dare to bring me an optical instrument as imperfect as the human eye, I’ll throw you down the stairs!” Thus, half jestingly, spoke the noted German physicist and physiologist HELMHOLTZ to one of his assistants. As remarkable an organ as the human eye is, it nevertheless is more readily deceived than the ear, and is in many ways far inferior to the eyes of animals.

The eye may be likened to a continuously-operating miniature camera. An enclosure—the eyeball itself—contains a lens, whose refractive action is aided by the watery fluid in front of it and the jelly-like substance behind it. Together, they cast an image of what is seen onto the eye’s sensitive



Cross-section of the human eye

“film”—the **retina** (see diagram). In the retina are delicate nerve-endings—so many and so small that it takes about 40,000 of them to cover the area of the head of a pin. They communicate what is seen to the brain. The **iris**, a variable-

sized diaphragm in front of the lens, controls the amount of light entering the organ. It corresponds to the “stop” of a camera.

In a darkened room, close one eye by placing your hand over it and hold a candle or other small light two or three inches from and a little to one side of the open eye. Move the light up and down while staring ahead into the dark. You will see branched, dark shadows on a dull red ground. These are shadow pictures of the network of blood vessels covering the retina.

The retina produces an exceedingly light-sensitive chemical called the **visual purple**, which is affected by light in much the same way as the chemicals on a photographic film, except that the images in the eye are always changing and the supply of visual purple is always being renewed. When you enter a dark theater from out of doors, you have difficulty in seeing clearly for some time. It takes several seconds for the iris to open and for the supply of visual purple, which is bleached out by the strong light, to renew itself.

Not all parts of the retina are equally sensitive. There is a very sensitive region near the branching point of the nerves called the **yellow spot**. In order to see clearly an object like a



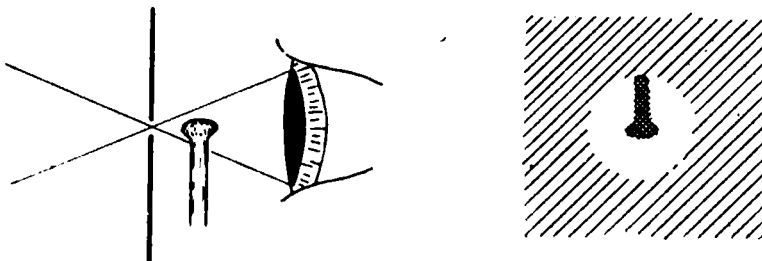
• *To find the blind spot*

high-flying bird or airplane, its image must be made to fall on the yellow spot. The branch point itself of the optic nerve is insensitive to light. It is called the **blind spot**. To show its

existence, hold the book over a foot away, keeping your left eye closed. Look at the cross in the accompanying figure. The black dot and the small square are also seen. Now, continuing to look at the cross, bring the book closer and closer to your eye. At a certain distance the dot disappears, its image then falling on the blind spot; move the book still closer and the square vanishes, but the dot reappears.

From what you have learned about converging lenses (page 194) you know that the image on the retina must be upside down. Why, then, don't we see everything around us turned wrong way up—chandeliers sprouting from the floor and furniture hanging from the ceiling? The reason is that from earliest childhood we have learned to *interpret* the inverted images as being re-inverted. The process of getting this training is probably responsible for a great deal of the difficulty a baby experiences in learning to walk.

Here's a way to convince yourself that the retinal images are really inverted: When you place an object very close to a lens, it cannot form a real image. Using a table lamp, cast a shadow of a pencil by holding it a few inches from a sheet of paper. Bringing a lens of not too short focus just in front



We really see things upside down

of the pencil does not reverse or otherwise change the shadow, except to make it slightly smaller and diffuse. Now prick a hole in a card with a pin, hold the perforated card about half

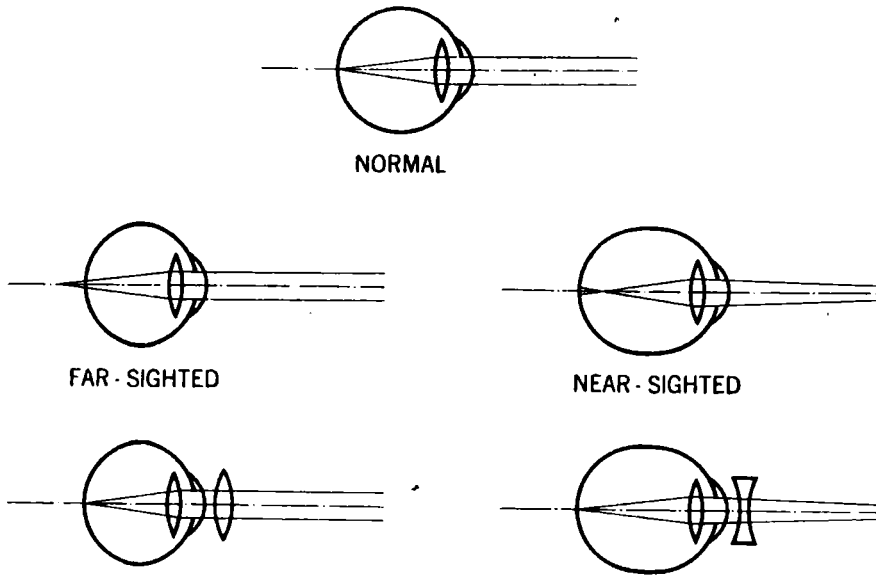
an inch in front of one eye and look at a bright surface such as a lampshade or the sky. Grasping the pin by its point, hold it between the card and your eye and bring its head upward in front of the hole. You will see a shadow picture of the pin moving *downward* across the hole. We know from the lens experiment that the shadow on the retina is right side up; the brain, however, interprets it as being upside down.

Have you ever wondered why Nature gave each of us two eyes rather than one? The same question arose on page 104 in connection with the ears. In both instances, the reason is the same: to enable us to locate and better perceive objects in space. The two eyes see an object a little differently, the separation of the eyes permitting you to look around the sides of the object, in a certain sense. You interpret this by ascribing depth to the thing viewed. The **stereoscope** that used to be found on every living room table two or three decades ago permitted each eye to view separately two pictures of an object taken from slightly different positions. The effect was to make the scene stand out in space.

Hold a pencil, point up, at arm's length and with one eye closed try to bring the extended forefinger of the other hand down to meet the point with a prompt, sweeping motion. Or try threading a needle with one eye shut. Invariably you'll miss; without two-eyed vision it's hard to judge distances.

To focus your camera on far or near objects you move the lens toward or away from the film. If your eye focused by the same method, its front surface would have to bulge out about $\frac{1}{4}$ inch when fixing on a nearby object. Instead, the eye changes its focus by a different method—muscles surrounding the flexible lens squeeze it together for near view or let it relax to its normal thinner shape for distant objects. This

power of **accommodation**, which enables a normal eye to see things as close as four or five inches and at all greater distances, decreases with age. A near-sighted eye is one that is too long, front to back, for the lens to be able to form a sharp image on the retina; the rays cross too soon. Prescribing

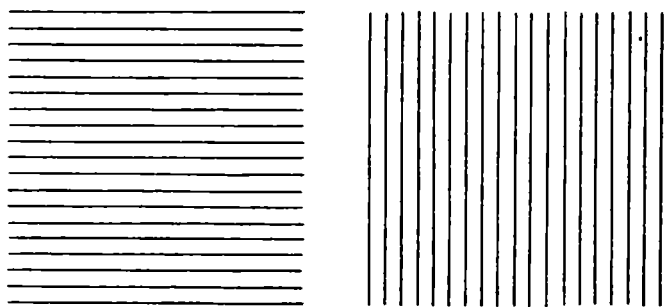


Near- and far-sightedness corrected with lenses

glasses consisting of diverging lenses corrects the trouble, as the diagram shows. In a far-sighted eye the rays encounter the retina before crossing, and an additional convex eyeglass lens is needed to remedy the difficulty.

A rather common eye defect is **astigmatism**, and it shows itself most readily in the inability of such an eye to focus vertical and horizontal lines at the same time. A normal eye sees both sets of lines in the following diagram with equal distinctness in all positions. If your eyes are astigmatic, however, there will be a certain distance at which the vertical lines seem sharp while the horizontal set is blurred; at another distance the reverse will be true. Rotating the page around the line of sight makes first one set and then the other appear

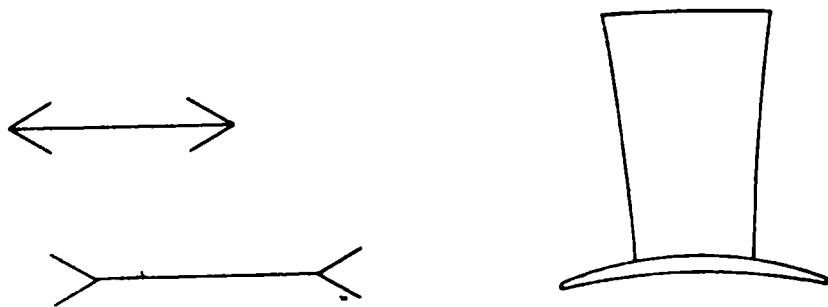
sharp. The trouble with an astigmatic eye is that the front surface of the eyeball is not curved equally in all directions, like a sphere, but the surface is like the side of an egg—curved most in a certain direction and least in the direction



Are you astigmatic?

at right angles. The defect is corrected by prescribing a cylindrical lens—one that is curved in only one direction. Of course, if there is both astigmatism and near- or far-sightedness, the two kinds of lens needed for correction are combined in a single piece of glass.

Besides optical defects of the eye, the sense of sight is often subject to mistakes in *interpreting* what is seen. Everybody knows that there are optical illusions that make it risky to

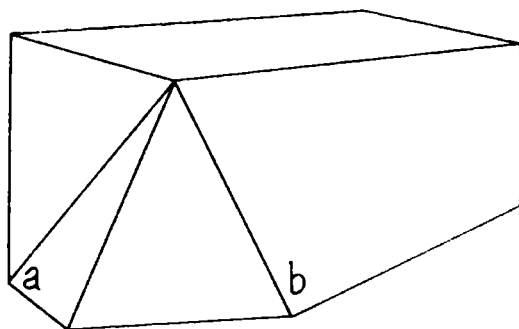
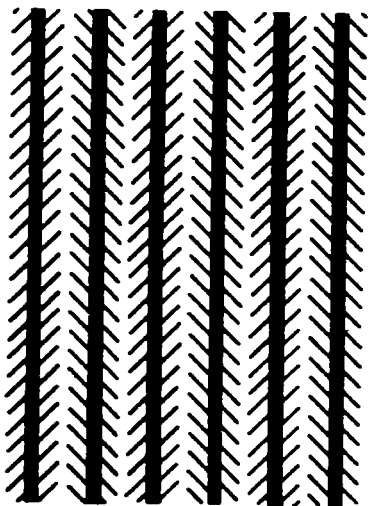


Don't trust your eyes . . .

conclude always that “seeing is believing.” Test your judgment of length with the accompanying figures. Which of the two horizontal lines is longer? Is the crown of the hat taller

than the brim is wide? Verify by measuring off with a strip of paper.

In the next diagram, test your judgment of angles. Are the heavier lines in the left hand drawing parallel? Check up by holding the page horizontal at eye level and sighting along



. . . they may tell lies

these lines. In the right hand figure, are angles *a* and *b* greater or less than right angles? Test by fitting the corner of a card to them.

Probably you have noticed many times how startlingly large the moon or sun appears to be when just rising or setting. "Appears to be" is correct, for the effect is merely an illusion, an error of interpretation. Hold a pencil at extreme arm's length and you will just be able to cover the full moon with the end of the pencil, regardless of whether the moon is near the horizon or high in the sky. The reason it looks much bigger in the former position is that we judge size by comparison with familiar objects. When it has just risen, we see the moon or sun near in direction to houses, trees, etc. We say to ourselves unconsciously, "The moon is much bigger

than a house." When high overhead, there is nothing nearby for comparison, and we no longer get the illusion of great size. We have learned not to be fooled this way as regards the size of an ordinary object on the surface of the earth; we expect it to "shrink" as it goes away from us. A ten story building a mile away can be hidden behind a pencil held a little less than 15 inches from your eye. In order to cover the building with the pencil held at arm's length, you would have to be somewhat over two miles away, and the building would then appear to be about as large as the full moon.

An amusing illustration of our ingrained habits of viewing familiar things from given distances is trying to walk along a straight line on the floor while looking at your feet through an opera glass. You'll find it nearly impossible to avoid missteps when holding the glass in the usual way, and essentially as difficult when using it turned about so that your feet seem small and far way. Try looking at your feet through the opera glass as you ascend stairs.

The retina holds jealously the fleeting images that flash across it. Your eye retains an impression for about $\frac{1}{8}$ second after the light is cut off. This **persistence of vision** is what makes movies possible. A series of separate pictures is projected on the screen at the rate of 24 each second, and your eye blends this sequence into a continuous moving picture. Hold a coin in an upright position on a smooth table by touching your forefinger lightly to the top edge. Snap one side of the coin with the middle finger of the other hand, setting it spinning. Persistence of vision makes the whirling coin look like a shining, solid ball. Stick pins into opposite edges of a thick card about two inches square to form an axle about which the card can turn. Prop up two forks between books to support the axle. Draw a picture of a canary on one

side of the card, then turn it over about the axle and draw a picture of a bird cage. Support the card on the forks, set it spinning with a flick of the finger, and you'll see the bird inside the cage. Hold a pencil lightly between thumb and forefinger at a point about a third the distance from one end. With the pencil at about eye level, move your hand rapidly up and down through a short distance. The pencil, you'll find, appears to be made of rubber, apparently bending into a curved form as it is shaken. Can you explain it?

The processes by which the eye detects color are not yet fully understood, but it seems likely that the main features are explained by the idea that there are three sets of color receivers in the eye, one responding mainly to red, another to green and a third to blue. A color-blind eye lacks sensitivity in one of these sets, the red being most commonly at fault. Many people are color blind to some extent without realizing it until their sight is tested for this defect.

The color receivers, like all other organs of the body, get tired under steady, uninterrupted use, producing a sort of temporary color blindness. Gaze steadily at a well-lighted colored object for about 15 seconds, then look at a white wall or ceiling and you'll see a spot of the complementary color. If the object is red, for example, the continued use of the red receivers tires them, and so for some time afterward this color does not register in the white light from the blank wall. The colored **after-images** seen for a while after looking at a bright light like the sun are due partly to other causes.

Place in a row on the table red, purple and blue pieces of cloth or paper so that adjoining ones overlap. The portion of the purple next to the red appears bluish, while the side adjacent to the blue surface seems more reddish. This is partly fatigue of the color receivers, partly mistaken judgment due

to different standards of comparison. Artists, designers and decorators must remember that the color of an object depends to some extent on that of the surroundings.

Don't be distressed if the following proceedings make you see spots before your eyes: Cut 16 squares, each about an inch on a side, out of black cloth or paper and lay them on a white surface in 4 rows of 4 each, with spaces of about a quarter of an inch between them. Let your eye wander over the set and notice the fleeting gray-black patches that are glimpsed at the crossings of the white "streets."

As a final experiment, cut out the disc on page 239 and paste it onto a thick card. Thrust a pin through the center and spin the disc, first in one direction and then in the other, under a bright light. Notice that the black and white pattern gives rise to color effects, and that the order of the colors reverses when the direction of spin is reversed. No completely adequate explanation in terms of fatigue has been given.

It may disappoint you to end this book with something that is not understood, but perhaps that's a good idea after all. Undoubtedly Nature will always be a step ahead of our understanding of her ways, but this does not mean that we cannot derive a great deal of deep, lasting satisfaction from contemplation of the world about us. The surest road to such an understanding lies over the firm ground of experiment.

. . . AND IF YOU WISH TO READ FURTHER——

- General: Richardson, E. G.: PHYSICAL SCIENCE IN MODERN
LIFE
Wendt, G. L.: SCIENCE FOR THE WORLD OF TO-
MORROW
Karlson, P.: THE WORLD AROUND US
Haas, A. and Freeman, I. M.: ELEMENTARY SURVEY
OF PHYSICS
- In connection with
chapter 1: Bragg, Sir William: CONCERNING THE NATURE OF
THINGS
1 to 8 incl.: Mott-Smith, M.: THIS MECHANICAL WORLD
9: Boys, C. V.: SOAP BUBBLES, THEIR COLOURS AND THE
FORCES WHICH MOULD THEM
10, 11: Jeans, Sir James: SCIENCE AND MUSIC
12, 13: Huxley, J. and Andrade, E.: SIMPLE SCIENCE
14, 15, 16: Bragg, W. L.: ELECTRICITY
Miller, D. C.: SPARKS, LIGHTNING, COSMIC RAYS
17, 18, 19: Bragg, Sir William: THE UNIVERSE OF LIGHT
19, 20: Houstoun, R. A.: LIGHT AND COLOR
20: Luckiesh, M. and Moss, F.: THE SCIENCE OF SEEING
Luckiesh, M.: VISUAL ILLUSIONS

INDEX

- Absorption
 - of colors 203
 - of radiation 117
- Acceleration 59
 - of gravity 60
- Accommodation, visual 225
- Action and reaction 62
- After-image 229
- Air
 - atmosphere 31-38
 - conditioning 124
 - pump 37
 - refraction of light 192
 - resistance 59, 66, 71
 - thermometer 106
- Airplane 67
- Alternating current 165
- Ammeter 160
- Ampère 160
- Ampere (unit) 156
- Archimedes
 - buoyancy 25
 - lever 42
- Astigmatism 225
- Atom
 - emission of light 155, 207
 - smashing 127, 147
 - Structure of 142
- Attraction
 - Electrostatic 139, 148
 - Gravitational 48
 - Magnetic 130, 132
- Barometer 34
- Battery, electric 152
- Bells, tone of 100
- Bernoulli 69
- Blind spot 222
- Boiling point 108, 123
- Bunsen
 - photometer 174
 - spectra 206
- Camera
 - Photographic 194, 195
 - Pinhole 172
- Candid mirror 180
- Candle power 173
- Capacity
 - Electrical 150
 - Heat 112
- Capillary action 83
- Cavendish 50
- Centigrade scale 108
- Centrifugal force 73
- Chlorophyl 204
- Clouds 126
- "Cold light" 155
- Color vision 229
- Colors
 - Absorption of 203
 - Complementary 203
 - Interference 217
 - of pigments 204
 - present in white light 199
- Commutator 162
- Compass 130
- Complementary colors 203
- Compressibility 16
- Condenser, electrical 150
- Conduction
 - Electrical 143, 153, 154
 - Heat 112
- Convection 114
- Copernicus 47
- Corpuscles, light 169
- Cosmic rays 148, 213
- Coulomb 149
- Crystal structure 22
- Current electricity 152-168
- Davy 114
- Decibel 92
- Declination, magnetic 135
- Density 15

- Descartes' diver 28
 Dew point 124, 126
 Diffraction 215
 grating 216
 Dip, angle of 136
 Dispersion 201
 Displacement 27
 Diving bell 14
 Door bell 160
 Dry cell 153
 Dry ice 127
 Dynamics 56
 Dynamo 163

 Earth, magnetism of 135
 Echo 89
 Eclipse of the sun 171
 Edison 155, 167
 Eddy currents 167
 Elasticity 17, 65
 Electricity
 Current 152-168
 Photo- 168
 Static 137-152
 Electromagnet 160
 Electromagnetic waves 169, 208-214
 Electron 142
 current 152
 emission from hot filament 167
 vibration 208
 Electrophorus 146
 Electroscope 139
 Energy
 Conservation of 128
 Heat 112, 127
 Kinetic 58
 Solar 116
 Equilibrium 53
 Evaporation 123
 Expansion
 by heat 106-110
 of freezing water 120
 Eye 221
 Eyeglass 225

 Fahrenheit 107

 Falling body, motion of 59-62, 66
 Faraday
 capillary action 84
 charge on surface of conductor 143
 electromagnetic induction 163
 lines of force 133
 Far-sightedness 225
 Floating 27
 magnets 132
 metals 81
 Fluorescence 209
 of watch dial 213
 Focal length
 of concave mirror 181
 of converging lens 194
 Focal point 89
 Fog 126
 Foot-candle 175
 Force 39
 Centrifugal 73
 lines of 133
 molecular attraction 79
 Franklin 139, 145
 Freezing point 108, 119
 Frequency
 of light vibrations 207
 of radio waves 166
 of sound vibrations 92
 Frictional electricity 137-152
 Frost 127
 Fundamental tone 95
 Fusion, heat of 120

 Galvani 152
 Galvanometer 160
 Gamma rays 212
 Gases 13, 21
 Generator, electric 163
 Gilbert 129, 135, 137
 Grating, diffraction 216
 Gravitation 46-55
 compared with electricity and magnetism 149
 Gravity 50
 Center of 51

- Ground connection 144
Guericke 35
Gyroscope 76, 78
- Hardness 17
Heat 105-128
 capacity 112
 energy 112, 127
 of fusion 120
 produced by a current 155, 158
 transfer 112-118
Helmholtz 221
Henry 163
Herschel 74, 91
Humidity 124
Huygens 215
Hydrometer 29
Hygroscope 124
- Illumination 173
Illusions, optical 226-228
Image 184
 in eye 221, 223
Impenetrability 14
Incandescent lamp 155
Inclined plane 44
Induction
 Electromagnetic 163
 Electrostatic 146
 Magnetic 132
 motor 167
Inertia 57
 Rotational 73, 75
Infra-red 209
Insulator
 Electrical 143
 Heat 114
Interference of light 217
Interferometer 220
Internal reflection: see Reflection,
 total
Interpenetration of Waves 87
Inversion of eye images 223
Ionosphere 180
- Ions
 in gases 143, 148
 in solutions 153, 154
Iris 221
- Joule 127
- Kepler 47, 197
"Kick" of a gun 62
Kirchhoff 206
- Leeuwenhoek 196
Leonardo da Vinci 87
Lens 192
 Converging 192
 Cylindrical 196, 226
 Diverging 196
Lever 42
Light 169-230
 Corpuscles 169
 Diffraction of 215
 Dispersion of 201
 Interference of 217
 Reflection of 175-186
 Refraction of 187-198
 Scattering of 210
 Velocity of 169, 205
Lightning rod 145
Lines of force 133, 159
Liquids 13, 21
 in motion 69
 Pressure exerted by 23
 surface forces 79-86
Loudness 92
- Magnetism 129-136
 Electro- 159
Magnification
 concave mirror 182
 converging lens 195
 microscope 198
 telescope 197
Magnifier, simple 196
Matter, states of 13, 21
Mayer 128
Mechanical advantage 41

- Mechanism 39-45
- Melting point 119
- Microscope 197
- Miner's lamp 114
- Mirage 192
- Mirror
 - Concave 181
 - Convex 184
 - Distorting 184
 - Plane 176
- Mixture, temperature of 110
- Molecular motion 21, 112, 128
- Molecules 14, 19-22
- Motor
 - Electric 162
 - Induction 167
- Motion 56
 - Laws of 59
 - of a falling body 59-62
 - pictures 168, 228
 - Rotational 73-78
- Music 94-102
- Musschenbroek 150
- Near-sightedness 225
- Neon tube 155
- Neutron 142
- Newton
 - gravitation 46
 - laws of motion 59
 - light corpuscles 169
 - spectrum 199
 - telescope 197
- Node 96
- Noise 91
- Non-conductor: see Insulator
- Octave 95
- Oersted 159
- Ohm 155
- Opera glass 197
- Organ pipe 97
- Overtones 96, 98
- Parachute 67
- Percussion instruments 99
- Persistence of vision 228
- Phantom Flower 182
- Photo-electricity 168
- Photography 194, 195
 - Infra-red 210
- Photometer 174
- Pigments, color of 204
- Pinhole camera 172
- Pitch 91
 - change due to motion 92
- Plato 169
- Poles, magnetic 129
 - of earth 136
- Potential, electrical 149
- Power 156
- Pressure 23
 - of air 31
 - of a gas 21
 - of a liquid 24
- Prism
 - binocular 197
 - dispersion 199
 - spectroscope 206
 - total reflection 191, 197
- Proton 142
- Pulleys 39
- Quantity of electricity 149
- Radiation
 - Absorption of 117
 - from the sun 116
 - heat transfer 116
 - types 208-214
- Radio
 - receiver 166
 - tube 168
 - waves 181, 213
- Radioactivity 212
- Rainbow 202
- Raindrops, fall of 66
- Ray 170
- Reaction 62
- Reflection 175
 - Total 190
- Refraction 188

- Refrigeration 122
Regelation 122
Repulsion
 Electrostatic 139, 148
 Magnetic 130, 132
Resiliency 17
Resistance
 Air 59, 66, 71
 Electrical 155
Resonance 101, 166
Retina 221
Ripple tank 89
Rocket 65
Roentgen 212
Rotation 73
 Planetary 74, 78
Rotor 162
Rumford 127, 174

Scattering of light 210
Screw thread 44
Shadow 170
Short circuit 158
Sight 221-230
Soap bubbles 84
 Color of 217
Solids 13, 22
Sound 87-104
 frequencies 92
 locator 104
 Speed of 88
 waves 88
Spectrochemical analysis 207
 Quantitative 208
Spectrograph 207
Spectroscope 206
Spectrum
 of sunlight 199
 lines 207
Splashes 80
Stars
 Temperature of the 107, 118
 Twinkling of 192
State, change of physical 119
Stereoscope 224
Stratosphere 35

Streamlining 71
Stringed instruments 94
Submarine 28
"Suction" 31
Sun
 Eclipse of 171
 Energy from 116
 temperature 107
Surface tension 79
Symmer 140

Telephone 166
 String 103
Telescope
 Reflecting 183, 197
 Refracting 197
Television 168, 213
Temperature 105
 of a mixture 110
 scale 107
Thales 137
Thermometer
 Air 106
 Mercury 107
Thermos bottle 114
Thermostat 109
Tone 91
 quality 97
Top, spinning 77
Torricelli 34
Transformer 164
Troposphere 35
Tuned circuit 166
Tycho Brahe 47
Tyndall 169

Ultra-violet 209

Vacuum 31
 as heat insulator 114
Vibration 88
 forced 102
 frequencies (sound) 92
 of electrons 208
 of pipes 98

- of plates and bars 99
- of strings 94
- Viscosity 16
- Vision 221-230
 - Color 229
 - Persistence of 228
- Visual purple 222
- Vitamins 209
- Volt 150
- Volta 152
- Volume 14

- Watt 156
- Wave length and color 205
- Waves
 - Diffraction of 215
 - Electromagnetic 169
 - in a rope 89

- Interference of 217
- Light 205
- Radio 181, 213
- Sound 88
- Water 87
- Wedge 44
- Weight 50
- Whispering gallery 89
- White light 199
- Wind instruments 97
- Wind tunnel 67

- X-rays 212, 216
- Xylophone 99

- Yellow spot 222
- Young 218
- Yoyo 75

